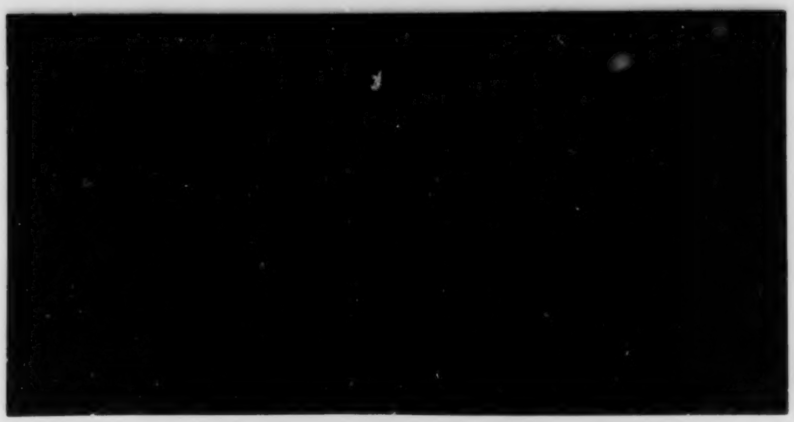
REPORT 34



SWEEP

SOIL AND WATER

ENVIRONMENTAL

ENHANCEMENT PROGRAM

PAMPA

PROGRAMME D'AMÉLIORATION

DU MILIEU PÉDOLOGIQUE

ET AQUATIQUE

Canada

Ontario

SWEEP

is a $30 million federal-provincial agreement, announced May 8, 1986, designed to improve soil and water quality in southwestern Ontario over the next five years.

PURPOSES

There are two interrelated purposes to the program; first, to reduce phosphorus loadings in the Lake Erie basin from cropland run-off; and second, to improve the productivity of southwestern Ontario agriculture by reducing or arresting soil erosion that contributes to water pollution.

BACKGROUND

The Canada-U.S. Great Lakes Water Quality Agreement called for phosphorus reductions in the Lake Erie basin of 2000 tonnes per year. SWEEP is part of the Canadian agreement, calling for reductions of 300 tonnes per year — 200 from croplands and 100 from industrial and municipal sources.

PAMPA

est une entente fédérale-provinciale de 30 millions de dollars, annoncée le 8 mai 1986, et destinée à améliorer la qualité du sol et de l'eau dans le Sud-ouest de l'Ontario.

SES BUTS

Les deux buts de PAMPA sont: en premier lieu de réduire de 200 tonnes par an d'ici 1990 le déversement dans le lac Erie de phosphore provenant des terres agricoles, et de maintenir ou d'accroître la productivité agricole du Sud-ouest de l'Ontario, en réduisant ou en empêchant l'érosion et la dégradation du sol.

SES GRANDES LIGNES

L'entente entre le Canada et les États-Unis sur la qualité de l'eau des Grands Lacs prévoyait de réduire de 2 000 tonnes par an la pollution due au phosphore dans le bassin du lac Erie. PAMPA fait partie de cette entente qui réduira cette pollution de 300 tonnes par an — 200 tonnes provenant des terres agricoles et 100 tonnes provenant de sources industrielles et municipales.

100-05260/

TECHNOLOGY EVALUATION AND DEVELOPMENT SUB-PROGRAM

SURVEY OF MOISTURE DISTRIBUTION BETWEEN TILE DRAINAGE LATERALS AND ITS RELATIONSHIP TO COMPACTION AND ROOTING DEPTH IN FLAT CLAY SOILS

FINAL REPORT

December, 1990

Prepared by:	STRATA ENGINEERING CORPORATION Don Mills, Ontario
Under the Direction of:	ECOLOGICAL SERVICES FOR PLANNING LIMITED, Guelph, Ontario - Subprogram Manager For TED
On Behalf of:	AGRICULTURE CANADA RESEARCH STATION, HARROW, ONTARIO N0R 1G0

EXECUTIVE SUMMARY

Three tile drained farms on flat, poorly drained Brookston clay soil in northern Essex County were studied with respect to soil moisture distribution between drainage laterals and its relationship to compaction, root growth, crop development, and yields. The survey type study was carried out under uncontrolled conditions in order not to interfere with the cropping program and schedule of the three farmer cooperators.

No significant increase in soil density (and hence compaction) was observed on one farm which had tomatoes in its rotation the year before the study. Mean dry densities were lower on this farm than on the other farms studied.

Information from this study suggests that a soil moisture content of 20%± represents optimum conditions for soil compaction on Brookston clay, and that agricultural equipment and implement traffic should be avoided at or near this moisture content, if possible. It was noted that soil moisture contents at harvest time are generally below 20%. Therefore, harvesting equipment and loaders for intensive cropping (tomatoes) should not pose a soil compaction problem on Brookston clay soil, unless there is a wetter than normal harvesting season.

Marked soil cracking was observed on all farms during the summer months. Principally because of these cracks, summer rains percolate very quickly below tile drain invert level. This tendency for relatively quick drainage during summer months is felt to be limiting adequate wetting of the root zone, and may also be contributing to undesirable removal of soil nutrients.

Due to the small number of farms and the overview scope of this study, firm conclusions could not be drawn for all parameters studied. Some observed trends require confirmation through further specific dedicated research, under controlled conditions, as outlined in the recommendations given in this report.

TABLE OF CONTENTS

TABLE OF CONTENTS - continued

TABLE OF CONTENTS - continued

LIST OF TABLES

LIST OF FIGURES

SURVEY OF MOISTURE DISTRIBUTION BETWEEN TILE DRAINAGE LATERALS AND ITS RELATIONSHIP TO COMPACTION AND ROOTING DEPTH IN FLAT CLAY SOILS

Technology Evaluation and Development (TED) Subprogram of the
Soil and Water Environmental Enhancement Program (SWEEP)

Agriculture Canada - Supply and Services Canada

DSS File No. 02 SE 01686-8-TED-19

1.0 INTRODUCTION

Agriculture Canada, through Supply and Services Canada, has awarded Strata Engineering Corporation a contract to execute a survey of soil moisture distribution between tile drainage laterals and to investigate its relationship to compaction and rooting depth in flat clay soils in southwestern Ontario. The study forms part of the Technology Evaluation and Development (TED) sub-program of the Soil and Water Environmental Enhancement Program (SWEEP). This report is submitted in fulfilment of the requirements of SWEEP-TED Contract 01686-9-0063.

1.1 Terms of Reference

The primary purpose of this study was to assess the effect of soil moisture content on soil compaction and crop rooting depth in the flat clay soils of southwestern Ontario.

At the start up meeting with the Scientific Authority from Agriculture Canada, experts from Ecological Services for Planning (ESP), and field officers from the Ontario Ministry of Agriculture and Food (OMAF), the terms of reference were agreed to cover the relationships, if any, between soil moisture, soil compaction and location of tile drainage laterals, and their influence on root growth, crop development, and yields. It was agreed that root development would be visually determined. Plants were to be harvested for biomass determinations and yield measurements.

Soy beans were selected as the index crop for all experimental sites.

A draft final report was submitted to Agriculture Canada in March, 1990. The report pointed out deficiencies in data due to lateness of start of the project. Therefore, a minor extension of the study was granted to evaluate spring 1990 conditions.

The results of more recent field observations and additional soil cracking laboratory simulation studies are incorporated in this final report.

1.2 Scope of study

The scope of the work undertaken included:

- Extensive literature review;

- Selection of farm sites and farmer cooperators for measurement of certain variables;

- Development of survey methods and appropriate experimental design and measurement of interacting variables such as:

  - compaction;
  - moisture content, soil moisture tension;
  - soil physical characteristics, including soil cracking;
  - drain type, spacing, gradient and depth;
  - hydraulic conductivity;
  - water table levels;
  - plant height;
  - varietal information;
  - root development;
  - crop yields;
  - rainfall;

- Recording of previous and current crop rotation, cultivation and management procedures (cropping history);

- Reporting procedures, including the completion of two quarterly reports, a preliminary and a draft final report;

- Farmer cooperator selection, contacts, and ongoing liaison;

- Crop harvesting, and selection of plants for root development study;

- Analysis of experimental results;

- Determination of relationships between variables and trends observed;

- Recommendations for further work based on the data and analyses.

2.0 STUDY OBJECTIVES

The stated objectives in the study proposal (RFP) from Agriculture Canada were as follows:

Through a survey of tile drained fields on flat clay soils with various drain spacings and gradients:

1. Study relationships between subsurface drainage and degree of compaction, hydraulic conductivity and crop root development.

2. Assess the drainage systems in the fields surveyed in terms of conformity with recommended spacings and depths based on the Drainage Guide for Ontario (OMAF Publ. 29).

3. Provide recommendations on research needs and approaches to validate and apply such relationships.

Minor variations from these initial study objectives were necessary due to ideal conditions not being available during the term of the study. All changes to the study terms of reference were pre-approved by mutual discussion and agreement with the Scientific Authority.

3.0 LITERATURE REVIEW

3.1 Previous and Related Studies

A number of studies have been conducted which are similar in scope and content, or are related to the current investigation. The more relevant of these are treated below.

Jamison et al.(1950) noted for a clay soil that the depth to which compaction was observed was nearly as great in the moist as in the wet soil condition. The soil, when dry and loose on the surface, was quite resistant to the compaction effect of a tractor tire. Further studies of this type were done by Weaver and Jamison (1951).

Bolton and Aylesworth (1959) working on Brookston clay at Woodslee, Ontario, studied the effect of tillage traffic on certain physical properties of Brookston Clay and also the effect on crop yield. The effects of high tillage on pore space in the soil were small and they could find no association between porosity and crop yield for this soil.

The effect of soil compaction on plant growth, development, and yield has been studied extensively in Canada (Bilanski and Varma, 1976; Raghavan et al., 1978; Negi et al., 1980; Taylor et al., 1981). McKyes et al.(1979) measured soil bulk densities, moisture retention characteristics and crop yields on a clay soil in Québec for a corn crop with different combinations of tractor traffic and tillage treatments. Optimum soil dry bulk densities were indicated for particular years with wetter and dryer growing seasons.

Raghavan and McKyes (1983) found that growth performance of corn plants on clay soil was best in moderately compacted plots. Yields increased with increasing tire contact pressure, reached a peak, then rapidly decreased with further increase. A similar relationship was observed between yield and dry bulk density.

Gameda et al. (1985) produced a comprehensive review paper on subsoil compaction and crop response.

A paper on subsoil compaction in a clay soil (Gameda et al., 1987) showed that soil moisture contents during compaction significantly affected clay soil bulk density distribution under high axle loads. Fall tillage and over-wintering removed the effect that soil loading under dry conditions had on topsoil bulk densities, but they were not as effective in reducing topsoil bulk densities resulting from loading under wet soil conditions.

Compaction and the surface structure of Brookston clay loam was studied by Stone (1987) by examining the cumulative contribution of surface soil compaction to soil structural deterioration and its relationship to corn and soy bean productivity. Fall vehicle compaction of the surface soil at soil moisture contents suitable for tillage did not significantly cause soil structural deterioration or limitation of productivity for the two crops studied.

Irwin et al. (1987) performed analysis of tile drainage discharge data to evaluate a drainage coefficient for Brookston clay soil. The probability of an annual drainage coefficient of 11.5mm/day was found to be 50%.

Larney et al. (1988) investigated the effects of subsurface drain spacing on the soil moisture regime of naturally poorly drained Clermont silt loam. The data indicated that a drain spacing of 20m resulted in a drier soil moisture regime than 40m spacing, but was not substantially different from 5m or 10m drain spacings.

3.2 Soil Compaction

Theories of soil compaction have been advanced for a number of years in the soil mechanics discipline for civil engineering applications, such as road building, compacted earth fill dams and other earth structures.

The standard measure of soil compaction throughout the world is the Proctor density, named after R.R. Proctor (1933). The American Society for Testing and Materials (ASTM) recognizes two standards, known as the Standard Proctor and the Modified Proctor (respective ASTM designations are: D 698 and D 1557). The compaction of any soil can be measured relative to these standards.

A representative sample of the soil whose field compaction is to be measured is mixed at different moisture contents (dry weight basis) and compacted with a standard energy in a standard mould. The moisture content (x-axis) is then plotted against dry density (y-axis). The resultant curve is parabolic in shape. The dry density of the soil increases with increasing moisture content to a value known as the optimum moisture content.

At moisture contents in excess of the optimum, the dry density decreases. Proctor (1933) attributed the shape of the moisture-density relationship curve to effects of capillarity at the lower moisture contents and lubrication at moisture contents above the optimum.

Hogentogler (1936) advanced an alternative theory of soil compaction to that proposed by Proctor and named it the "viscous water theory". This theory stated that the first layer of water adsorbed on to the surface of the soil particle was more viscous than the second layer, and so on. At low moisture contents, the closely bound soil particles would offer greater resistance to compaction, whereas at the higher moisture contents the soil would shear readily due to lower viscosity of the water between soil particles.

Lambe (1960) attempted to explain the shape of the moisture-density curve in terms of surface chemical theories. As more water is added the electrolyte concentration decreases in the pore water, thus causing a general repulsion of clay mineral particles by the formation of stronger double layers.

Olson (1963) postulated an "effective stress" theory of soil compaction, basing it on principles by then well developed in the field of soil mechanics.

In agricultural applications the effects of tillage and cultivation equipment on soil compaction have been reported by several researchers (Gill and Reaves, 1956; Soehne, 1958; Rao et al., 1960; Lyles and Woodruff, 1963; Van Doren et al., 1964; Arndt and Rose, 1966; Djokoto et al., 1970; Feldman and Domier, 1970; Soane, 1970; Barnes et al., 1971; Amir et al., 1976). The general consensus is that traffic from agricultural implements and equipment does affect crop growth and yield on several types of soils studied.

The measurement of soil compaction in agricultural applications has been by means of penetrometers of various design and complexity (Waelti et al., 1963; Freitag, 1968), and the measurement of pore volume and porosity by oxygen diffusion and similar measurements (Lemon and Erickson, 1952).

Developments following WW II led to the refinement and production of nuclear devices for measuring both soil moisture and in-situ dry or wet densities. This subject is discussed in more detail later in this report.

3.3 Hydraulic Conductivity

The determination of hydraulic conductivity is an important factor in determination of soil drainage characteristics. Hydraulic conductivity can be empirically estimated from pore or grain size distribution of the soil. As yet, such methods do not appear to be universally reliable. Hence, hydraulic conductivity must be measured experimentally. The laboratory and field methods for determining hydraulic conductivity are extensively reviewed in the literature (American Society of Agricultural Engineers, 1962; Bouwer and Jackson, 1974; Daniel, 1989).

The auger hole test for hydraulic conductivity (Maasland and Haskey, 1958) is a widely used procedure. The single auger hole method has been used satisfactorily to determine hydraulic conductivity for the design of subsurface drains in Québec (Shady et al., 1976).

Unsaturated hydraulic conductivity of a tilled clay soil has been determined in Québec (Douglas et al., 1980). Field measurements of hydraulic conductivity have also been made by infiltration through artificial crusts (Bouma et al., 1971) and by an internal drainage method (Hillel et al., 1972). The Guelph Permeameter (Reynolds and Elrick, 1985) provides a cost effective, easily portable and convenient method of measuring hydraulic conductivity in the field.

Measurements of field saturated hydraulic conductivity by the Guelph and velocity Permeameters have been compared by Kanwar et al. (1989). For selected test sites and conditions, both permeameters provided reasonably similar values. The field measured hydraulic conductivity values tended to be much lower than laboratory values.

A comparison has been made of field hydraulic conductivity on two Ohio Soils by Dorsey et al. (1989) using various techniques for such measurements in situ. The three techniques used were the Guelph Permeameter, velocity permeameter and a pumping test method. The Guelph Permeameter, although convenient and easy to use, was found to produce lower permeability results than the other techniques, on heavy clay soils.

It is important to note that even on fields that are considered homogeneous, localised variations in hydraulic conductivity are common (Tabrizi and Skaggs, 1982).

3.4 Tile Drainage Formulae

Drain spacing equations generally describe the relationship between the physical characteristics of the soil, depth and spacing of subsurface drains, and the fall of the water table at the mid-spacing of the drains.

A number of such equations have been published. The more popular of these include Hooghoudt (1940); Guyon (1967); Kirkham (1958); Ernst (1956); Glover-Dumm (Dumm 1954, 1964); Van Schilfgaarde (1963, 1964); Bouwer and Van Schilfgaarde (1963); and Hammad (1962).

The Hooghoudt equation is quoted in the Ontario Drainage Guide, (Irwin, 1986) as the steady state drain spacing formula which is the most widely accepted and often used in practice in Ontario.

A field comparison has been made of transient drain spacing equations in a southern Alberta lacustrine soil (Buckland et al., 1987). The Bouwer and Van Schilfgaarde equation (Integrated Hooghoudt), using a C Factor of 1.0%, was found to most closely predict the measured performance of existing drains under all conditions. Other equations evaluated in this study were the Glover equations, the Van Schilfgaarde equation and the Hammad equations for thick and thin layers.

Sylvestre et al. (1989) investigated 30 subsurface drainage systems in Québec in clay and loamy soils to check whether the Guyon equation, on which they were designed, was adequate for drainage of the St. Lawrence Lowland soils. They found the Guyon model to be appropriate for the design of subsurface drainage systems in the Lowlands.

3.5 Soil Cracking

Soil cracking is a prominent feature of clay soils. Brookston clay may be affected by such cracking which would significantly alter the hydraulic characteristics under dry mid summer conditions.

Much of the early work on soil cracking was essentially by visual observations (Hardy and Derraugh, 1947). More recently limited measurements of crack lengths, widths and depths have been made and correlated with soil moisture (Yaalon and Kalmar, 1984).

van der Tak and Grismer (1987) studied irrigation, drainage and soil salinity in cracking soils. They estimated crack volume of Imperial clay, a Californian heavy montmorillonitic (smectitic) type clay, by observations of surface irrigation linear advance trajectories. Through this study they estimated the crack volume for this soil to be $1600 m^3/ha$.

An attempt has also been made to model the effects of soil cracks on water movement in soils (Hoogmoed and Bouma, 1980).

Hoover and Jarrett (1989) observed that more surface cracks and root channels facilitate surface venting and loss of entrapped air. The venting of air trapped in and around subsurface drains increased drain flow and decreased surface runoff.

3.6 Mole Drainage

Mole draining is extensively used in Europe, but the practice is not common in Ontario. Accurate information on the particular soil properties that make a soil suitable for mole drainage is not readily available. Theobald (1963) gives values for different countries and quotes a required clay content ranging between 20% and 50% with a sand content not in excess of 20%.

Rycroft (1972) gave a lower limit of 30% and an upper limit of 55% clay content for moling. Trafford and Massey (1975) indicated no less than 40% clay and no more than 20% sand for satisfactory moling.

Mole channels are subject to deterioration. Their working lifetime in fair to good conditions is in the order of 5 years, although much shorter (a few weeks) and much longer lifetimes (30-40 years) have been observed (Hudson et al., 1962). In Canada, mole drainage has been tested on swelling silicate clay soils (Bearbrook clay) in Eastern Ontario (Weil et al., 1989). Three years after installation, mole drains were found to have remained functioning and still open, with a few exceptions. Freeze-thaw cycles did not appear to have a detrimental effect.

3.7 Soil Moisture Tension

Soil matric potential has been measured for a Clermont silt loam by Larney et al. (1988). They found a general trend of increase in soil matric potential with increased distance from subsurface drains on this soil.

Kanwar (1989) investigated the effect of tillage systems on the variability of soil water tension and soil water. More variability in the soil water tension data was observed within the same tillage system than among the four different tillage systems tested in the study. This conclusion suggested that the variability in the soil water tension data could easily overshadow the tillage induced effects on soil water tension.

4.0 SITE AND GEOLOGY

4.1 Location

The site of all experimental work reported in this study was Essex County. The County is bounded by Lake St. Clair to the north, the Detroit River to the west and Lake Erie to the south. See Figure A4.1 in the Appendix for location of the experimental farms.

The farms on which the current studies took place are all in the Stoney Point, Tilbury,and St. Joachim areas of northern Essex County.

4.2 Geology

Pleistocene geology has influenced the parent materials on which Essex County soil are formed. Unsorted stoney materials were laid down by the glaciers in this area. Considerable amounts of coarse sediment and outwash materials were deposited by ablation as the ice melted and the ice front retreated.

The bedrock underlying Essex County is mainly limestone of Devonian age. The drift over all the County contains considerable limestone as well as significant amounts of shale. Some igneous rock material is also present.

4.3 Soil

The soils of Essex County have been grouped on a textural basis (Ontario Ministry of Agriculture and Food, 1939). The distribution of heavy, medium and light textured soils in Essex County is shown in the Appendix in Figure A4.1, which illustrates their natural drainage characteristics.

Poorly drained soils occupy a considerable area of the County and consequently their management is of extreme importance.

The current investigation was carried out on Brookston clay, a soil formed from lacustro-morainic materials and which exhibits poor natural drainage.

4.4 Drainage

Figure A4.2 in the Appendix is an outline map of the County illustrating the natural drainage system.

Essex County is predominantly flat in character with scattered sandy ridges and hillocks.

A number of small rivers and streams drain into the lakes and rivers which form the County boundaries.

The largest rivers in the area of this study are the Ruscom and the Belle which flow northward into Lake St. Clair.

Owing to the flat topography and the predominantly heavy textured soils, surface and subsurface drainage techniques are in extensive use throughout the study area in order to increase productivity. A number of farms have tile drain systems installed, many of which outlet into a network of open ditches and drainage canals which complement the County's natural streams and watercourses.

5.0 STUDY METHODOLOGY

5.1 Farm Selection

5.1.1 Selection Criteria

Criteria for experimental farm site selection were discussed and approved at a project start up meeting at Harrow Research Station on 1989 05 31. Three farm site selections were agreed upon, with the criteria given in Table 5.1.

The criteria for intensive cropping was the presence on the experimental site of an intensive cash crop (eg. tomatoes) the year before the study (i.e., 1988).

Due to difficulty in obtaining a farm site with standard tile spacing (4 rods) and intensive cropping (tomatoes) the originally approved criteria were modified as shown in Table 5.2.

Final farm selections and planting dates were as indicated in Table 5.3.

5.1.2 Soil Type & Crop

The soil type on each farm was Brookston clay loam (clayey, mixed mesic Typic Haplaquoll). The Brookston series is part of the group of soils formed from Lacustro-Morainic material.

The parent material is a heavy ground moraine which has been altered to a greater or lesser degree by wave action and lacustrine deposition. The parent material composition is dolomitic limestone intermixed with some shale. Table 5.4 shows the Textural Classification of Farms #1, #2 and #3.

Table 5.1 Initial Farm Selection Criteria

Farm Designation	1	2	3
Tile Spacing	Standard	Standard	Split
Cropping History	Less Intensive	Intensive	Intensive
Crop Cover	Soy beans	Soy beans	Soy beans

Standard Tile Spacing was 4 rods (20m approx); Split Tile Spacing was 2 rods (10m approx).

Table 5.2 Revised Farm Selection Criteria

Farm Designation	1	2	3
Tile Spacing	Standard	Split	Split
Cropping History	Less Intensive	Less Intensive	Intensive
Cover	Soy beans	Soy beans	Soy beans

Table 5.3 Farms Selected for Study

Farm Location	Crop Cover	Cropping History	Tile Spacing	Planting Date
#1* R. Chauvin Stoney Point	Soy beans	Intensive	1.5 rods	May 22
#2 R. Chauvin Tilbury Conc. 3	Soy beans	Less Intensive	2 rods	June 10
#3 H. Moison St Joachim	Soy beans	Less Intensive	4 rods	May 11

* Farms are numbered in the chronological sequence of their selection.

Table 5.4 Textural Classification of Farms Selected for Study

Farm #	Sand* %	Silt%	Clay%	USDA Classification
1	25	40	35	Clay Loam
2	28	37	35	Clay Loam
3	29	38	33	Clay Loam

* Includes particles larger than 4.75mm

On all three farms, the cover crop for the duration of the 1989 study was soy beans which, by agreement, was selected as the common index crop.

During the limited studies carried out on Farm #1 in 1990, the cover crop was winter wheat.

5.1.3 Cropping and Cultivation

Cropping histories previous to 1989 for each farm are shown in Table 5.5.

Table 5.5 Cropping Histories of Farms Studied

Farm #	History	Tile Spacing	Rotation			
			1989	1988	1987	1986
1	Intensive	1.5 rods	S	T	W	S
2	Less Intensive	2 rods	S	S	C	C
3	Less Intensive	4 rods	S	C	W	S

S = Soy bean W = Wheat C = Corn T = Tomatoes

The cultivation regime followed for each farm during the 1989 study growing season was as follows:

Farm #1 The field was disced in the fall of 1988 followed by the use of a Sabre plough (stiff chisel without spring loading). It was cultivated in the spring of 1989 with a Danish tined cultivator with land packer in tandem. Herbicide was sprayed at that time. Two such cultivations were performed.

The field was planted, and at post planting, part of the field was sprayed with herbicide.

There was no further cultivation or agricultural traffic on the field.

Farm #2 The cultivation regime was as for Farm #1 but fall discing was omitted.

Farm #3 Two discings were performed in the fall of 1988. In the spring of 1989 three passes were made with a spring loaded tine cultivator with land packer in tandem.

At planting, an 8" band of grass herbicide was sprayed.

Post planting operations were: cultivation weeder one pass, rotary hoe two passes, cultivator three passes.

The heaviest post planting cultivation was done on Farm #3.

5.2 Drainage Characterization

5.2.1 Tile Lateral Spacing

Actual measured tile lateral spacings for all three farms appear in Table A 5.1 in the Appendix which also records the depth to the tile lines which were studied. Tile lateral spacings were nominally 6.6m on Farm #1, 10m on Farm #2 and 20m on Farm #3. The type and size of the drain laterals are also indicated in Table A 5.1.

5.2.2 Survey Lines and Experimental Areas

The three selected farm sites were all of flat topography with slopes ranging between 0 and 0.6%. On Farm #1 and Farm #2, occasional shallow surface channels were observed. These

channels would presumably drain localised wet spots. On Farm #3 none of these channels were present in the vicinity of the experimental area.

On each farm, three adjacent tile laterals were located with individual outlets to a collector ditch rather than to a subsurface main. Two survey lines, designated SL1 and SL2, were laid out across the three tile laterals so selected. The survey lines were chosen far enough from the edge of the fields to avoid boundary effects and the effect of machinery turning on headlands.

The distance of the first survey line was set at 15m from the mid point of the collector drain on Farms #1 and #2, and 34m on Farm #3. Ground elevations, land gradient and other similar measurements were made at each farm site and along the survey lines.

In 1990 a supplementary survey line SL3 was set out on Farm #1 at 5m from the mid point of the collector drain to cater for the study of moisture characteristics.

5.2.3 Site Mapping/Surveying

Surveys were made of the experimental areas to establish the location of the drainage laterals, to tie in the survey lines in relation to the outlet ditches and to record other site features, such as gradients, roads, drainage structures and the like.

Plans of each 1989 experimental area are shown in the Appendix (Drawing Nos. S89257-A, S89257-B, S89275-C) along with the 1990 experimental area (Drawing No. S89257-D).

5.2.4 Laterals, Gradients

On each farm, levels were taken at every selected tile outlet and survey line for the three laterals under study. Using this information, gradients were computed for each tile line, and are given in Table A5.2 in the Appendix.

5.2.5 Piezometers

Piezometers were installed at each site in 1989, and on Farm #1 in 1990.

In 1989, on Farms #1 and #2, installation was completed on July 6 and 7, and on Farm #3 on July 27. Installation was delayed on Farm #3 due to difficulty in the final selection of this farm.

The piezometers were installed in 100mm diameter holes drilled to an average depth of 0.8m to 0.9m below ground surface, and at least 100mm below the invert level of the drain lateral. Extremely hard clay conditions (due to a preceding dry spell) made boring of the holes difficult, even with power auger equipment.

Each piezometer was nominal 1.5" (37.5mm) diameter PVC pipe with the lowest 100mm length being slotted and wrapped with geotextile fabric. These slotted standpipes were installed on a 25mm thick bed of coarse to medium sand placed at the bottom of each augered borehole which was then backfilled with medium sand to at least 100mm above the level of the uppermost perforation (slot). A bentonite seal was placed over the backfilled sand for a minimum thickness of 100mm. The seal was then hand-tamped into place, following which the remaining hole was backfilled with native soil. The top of each piezometer pipe was taped to prevent direct entry of rain. The general arrangement is shown in Sketch S89257-SK-1 in the Appendix.

The piezometers were installed across three tile lines along the two survey lines on each farm immediately adjacent to, and also at the mid point of the tile lines.

A total of 10 piezometers was installed at each farm in 1989. The general arrangement of the survey lines and piezometers is shown on Drawings S89257-A, -B and -C in the Appendix.

On 1990 04 25, on Farm #1, four piezometers were installed across three tile lines along a new survey line, SL3, close to the collector drain. The arrangement of this group of piezometers is shown on Drawing S89257-D in the Appendix.

5.2.6 Tensiometers

On 1990 04 25, four Tensiometers (model 2725 Jet Fill, by Soil Moisture Equipment Corp.) were installed along survey line SL3 on Farm #1 as shown on Drawing S89257-D.

Tensiometers T_1, and T_2 were installed at the mid point between two drain laterals while T_3 and T_4 were placed immediately adjacent to one lateral. T_1 and T_3 were installed 200mm deep and T_2 and T_4 300mm deep.

5.2.7 Rain Gauges

Rainfall information was collected on each site by the farmer cooperators. Simple, locally available point rainfall type rain gauges were used on each site. These gauges have a nominal 125mm capacity and are typically suitable for ground or aerial post mounting. The gauges were located far enough away from buildings, trees, and other obstructions, in accordance with standard practice, to ensure accuracy of readings.

The accuracy of these gauges is ±2mm.

One such rain gauge was installed at Farm #2, while existing instrumentation was already present on Farms #1 and #3.

A new gauge was also installed in close proximity to the Tensiometers and Piezometers on survey line SL3 for the studies in 1990.

5.3 In situ Measurements

5.3.1 Nuclear Moisture-Density Meter

In situ moisture content and dry density measurements were made with a Troxler Model 3440 Series Moisture-Density gauge. This instrument is designed to measure moisture content, density and compaction of soils, aggregates, and asphalt. The instrument complies with ASTM Standards D 2922, D 2950 and D 3017.

The Troxler Model 3440 has a single probe with a radioactive source at its tip and a detector in the body of the gauge. Measurements are taken by inserting the probe into the soil and reading the amount of radioactivity reaching the detector at the surface.

The attenuation of mono-energetic gamma radiation passing through the soil is related to both bulk density and moisture content. These values are indicated on the instrument's digital type display. The instrument is factory calibrated. Further details on its principles of operation and use appear in the Appendix.

The effectiveness of the instrument for soil moisture and density measurements has been evaluated by Gameda et al. (1987).

5.4 Field Studies

5.4.1 Visits, Observations and Measurements

Visits were made to the project area for meetings, farm selection, installation of instrumentation, field measurements, collection of farmer cooperator data, and harvesting. A schedule of visits made, including the reason for each visit, is included in the Appendix.

During 1989 visual observations and measurements were made of crop height and water table levels in the piezometer standpipes at each field visit.

In 1990 measurements at two day intervals were made of water table levels and tensiometer readings on Farm #1.

5.4.2 Precipitation

Precipitation data was collected by farmer cooperators and the recorded amounts were collected by Strata personnel at monthly intervals.

5.4.3 In Situ Moisture-Density

Moisture content and density determinations with the Nuclear Moisture Density meter were made at two depths, 100mm (4") and 200mm (8") along Survey Lines 1 and 2 on each farm.

These readings were taken at spatial intervals along each survey line of approximately 3.3m on Farms #1 and #3, and 5m on Farm #2. During 1990, moisture content and density determinations were made along Survey line 3 on Farm #1 and also at two non cultivated control points on this farm.

5.4.4 Crop Condition and Growth

On each field visit in 1989, observations were made of crop growth and plant height. Plant height was measured from the soil surface to the top of the last fully developed leaf. Supplementary information was obtained on crop condition through a crop specialist from the Stoney Point Farmers Cooperative. His report is reproduced in the Appendix.

5.4.5 Field Soil Sampling

Bulk soil samples were taken by hand along Survey Lines at each site corresponding to the depth and location of randomly selected individual Nuclear Moisture Density meter reading sites. Five or six such samples were taken at each visit from each farm .

Bulk soil samples were also taken from each site for Proctor Density determinations.

In all cases, soil samples taken from the field were transferred to moisture proof plastic bags or containers, sealed and immediately transported to the laboratory for further testing.

5.4.6 Hydraulic Conductivity Measurements

Hydraulic Conductivity measurements were made on Farm #1 only in 1989. The Guelph Permeameter was used. Four different locations were randomly selected in close proximity to Survey Line 1 on Farm #1. Two sets of readings were taken at each of these locations, using recommended procedures for this permeameter.

In 1990, similar measurements were made on Farm #3 again at four random locations in close proximity to the previous position of Survey line 1 on that farm. Two sets of readings were taken at each of these locations.

It was not possible to take hydraulic conductivity readings on Farm #2 because of a change in tenancy of that farm.

5.4.7 Crop Harvesting

Harvesting of the experimental areas had to be conducted to suit each farmer cooperator's harvesting schedule. As a consequence, the three farm sites were harvested on different dates immediately before or at the time of farmer harvest.

Farm #3 was harvested on 1989 09 28, and Farms #1 and #2 on 1989 10 02. On each farm, a swath 1m wide was marked out along each survey line, covering the distance between three tile lines i.e. the swath covered the approximate length between the 5 piezometer installations on each survey line.

In each case, all plants were hand harvested and the entire mass of harvested material weighed by a hand held hook type scale. The harvested material was threshed by a small plot harvester (Hege Model 125B) provided by the Harrow Research Station. Weights of threshed grain from each experimental area were taken and the grain was sent to Harrow Research Station for moisture content and further yield determinations.

At harvesting, all experimental equipment, stakes, and piezometer standpipes were removed.

5.4.8 Root Development

Individual soy bean plants along the survey lines at each farm site were carefully removed with soil and roots intact, for root development determinations in the laboratory.

5.4.9 Measurement of Soil Cracking

A simple but effective field method was devised to measure the volume of soil cracking in the upper 0 to 200mm of the soil on Farm #1. The method consisted of carefully removing a cylinder (300mm diameter, 200mm deep) of soil sufficiently large to include cracks. This soil was then weighed immediately in the field. Soil volume was determined by lining the resulting excavation with a thin plastic film pressed tightly against the side and bottom of the excavation. Water poured from a measuring cylinder to the level of the original ground surface indicated the volume of the hole (or the soil removed). The plastic liner and the contained water were carefully removed and weighed to verify the volume obtained by the measuring cylinder. Samples were taken from the cylinder of excavated soil for laboratory determinations of moisture content, porosity, bulk density and unit weights.

This procedure was performed at two locations near Survey Line 3 on Farm #1 in each of the months of April, June, and July, 1990, to compare spring (non cracked) with summer (cracked) soil conditions.

5.5 Laboratory Studies

5.5.1 Moisture Contents

Natural moisture content determinations were made on soil samples taken from the Survey Lines on each farm site. Portions of the samples were weighed, oven dried then weighed again for computation of gravimetric moisture content.

5.5.2 Atterberg Limits

Atterberg limit tests to determine the Liquid and Plastic Limits and Plasticity Index were performed in accordance with ASTM Standards D 423 and D 424. The results are plotted on Figure A6.1 in the Appendix.

5.5.3 Densities and Specific Gravity

Laboratory density determinations were made on field samples for correlation with nuclear moisture-density meter measurements. Density determinations were made on irregular shaped soil samples using a wax coating method. Specific gravity determinations were also made for soil samples at different depths (ASTM D 854).

Proctor Density tests were performed on the bulk soil samples obtained from each farm. Both Standard Proctor (25 blows per layer, 3 layers, 12.5kg hammer) and a "Modified" method using only 10 blows per layer with the same hammer, were performed.

5.5.4 Root Development

Plant specimens collected from each farm were visually examined in the laboratory and root lengths and diameters measured with calipers.

5.5.5 Soil Cracking

Laboratory observations were made of the commencement and extent of cracking of a crushed and sieved combined sample of soil from the farms. The soil was mixed to initial moisture contents in the order of 35 - 50%, and allowed to cure in an enclosed plastic container for a week. The wet soil was then placed in non-stick baking dishes to a thickness of 10mm± and allowed to air dry until cracking occurred. After crack development ceased, the pan and soil were dried in an oven to constant weight for determination of initial, intermediate, and final moisture contents. Photographs illustrating the laboratory experiments are included in the Appendix.

6.0 STUDY RESULTS

6.1 Approach and Expectations of Research

This study was conducted on farms, rather than on an experimental scale or in a controlled manner, and as such, there was no control over treatments, eg. variety of crop grown, management, cultivation procedures, planting dates, and management practices. The dates of harvesting were decided in each case by the farmer's harvesting schedule. All field experimental equipment had to be removed at harvesting in order not to disrupt any of the farmer's fall tillage schedule. Consequently, post harvest information could not be obtained. Precipitation readings were taken by the farmer at each site. On at least one date in 1989, there was no measurement of precipitation given on two farms, although visits to each site indicated measurable rainfall, based on the observed wetness of the ground.

Experimental observations for the 1989 study commenced in the summer, well after seeding. Thus, observations of drainage characteristics, soil moisture, soil cracking, and the prevailing groundwater conditions could not be made in the spring of 1989.

Limited information on late spring moisture characteristics was obtained in 1990 following an extension of the study. Piezometers and tensiometers were installed on Farm #1. Measurements at two day intervals were taken of water levels and soil water tension. Moisture content, density and preliminary soil cracking studies were also pursued. Rainfall recording was better organised to improve the reliability of the data collected.

Bearing in mind the above, the approach taken in this study has been to measure as many interacting variables as possible within time and budget constraints, and to analyze these for trends and relationships. These qualifications and limitations must therefore be factored into the research results and the conclusions reached.

6.2 Field Measurements

6.2.1 Moisture Content Determinations

Moisture content values, as determined in the field during 1989 site visits using the Troxler Nuclear Gauge, are given in Table A6.1 in the Appendix. Values of moisture content on Farm #1 in 1990 are reported in Table A6.2.

The moisture content values (Troxler) show considerable variation, no doubt related to differences in precipitation over the study period. The values obtained in 1989 vary between 11.5% and 27.1% (all farms). Higher mean moisture contents were observed on Survey Line 1 for Farms #1 and #2 but not on Farm #3 where the equivalent Survey Line was further from the drainage outlets.

The Troxler measured mean moisture content values are shown in Table 6.1.

Table 6.1 Mean Moisture Contents (% Dry Weight) 1989

Survey Line	SL 1	SL 2
Farm #1	19.35	17.51
Farm #2	20.23	18.23
Farm #3	19.37	20.20

The mean moisture content values given in Table 6.1 are averages of all readings taken on both Survey Lines during the field visits of July, August, and September, 1989.

Mean soil moisture contents, as measured with the Troxler unit at depths of 100mm and 200mm, are shown in Table 6.2.

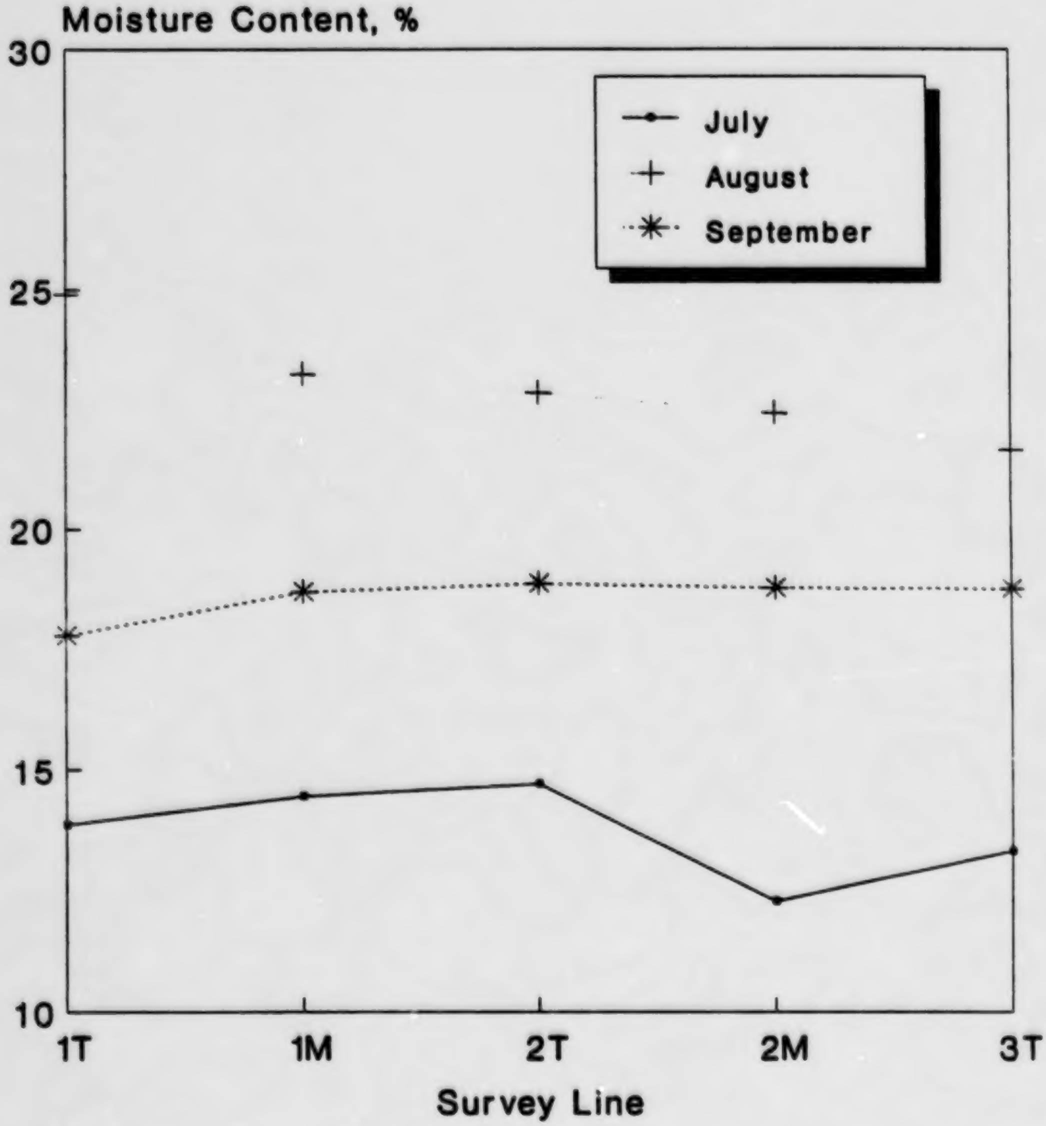
Moisture contents at the mid point between tile lines were compared with moisture contents immediately above the tile line locations, and the results are shown graphically in Figures 6.1, 6.2, and 6.3.

Table 6.2 Comparison of Mean Moistures (Troxler) at Two Depths, 1989

	Mean Moisture Content % at depths of		
	100mm	200mm	Combined
Farm #1	19.10	17.77	18.43
Farm #2	19.61	18.86	19.23
Farm #3	20.40	19.00	19.70

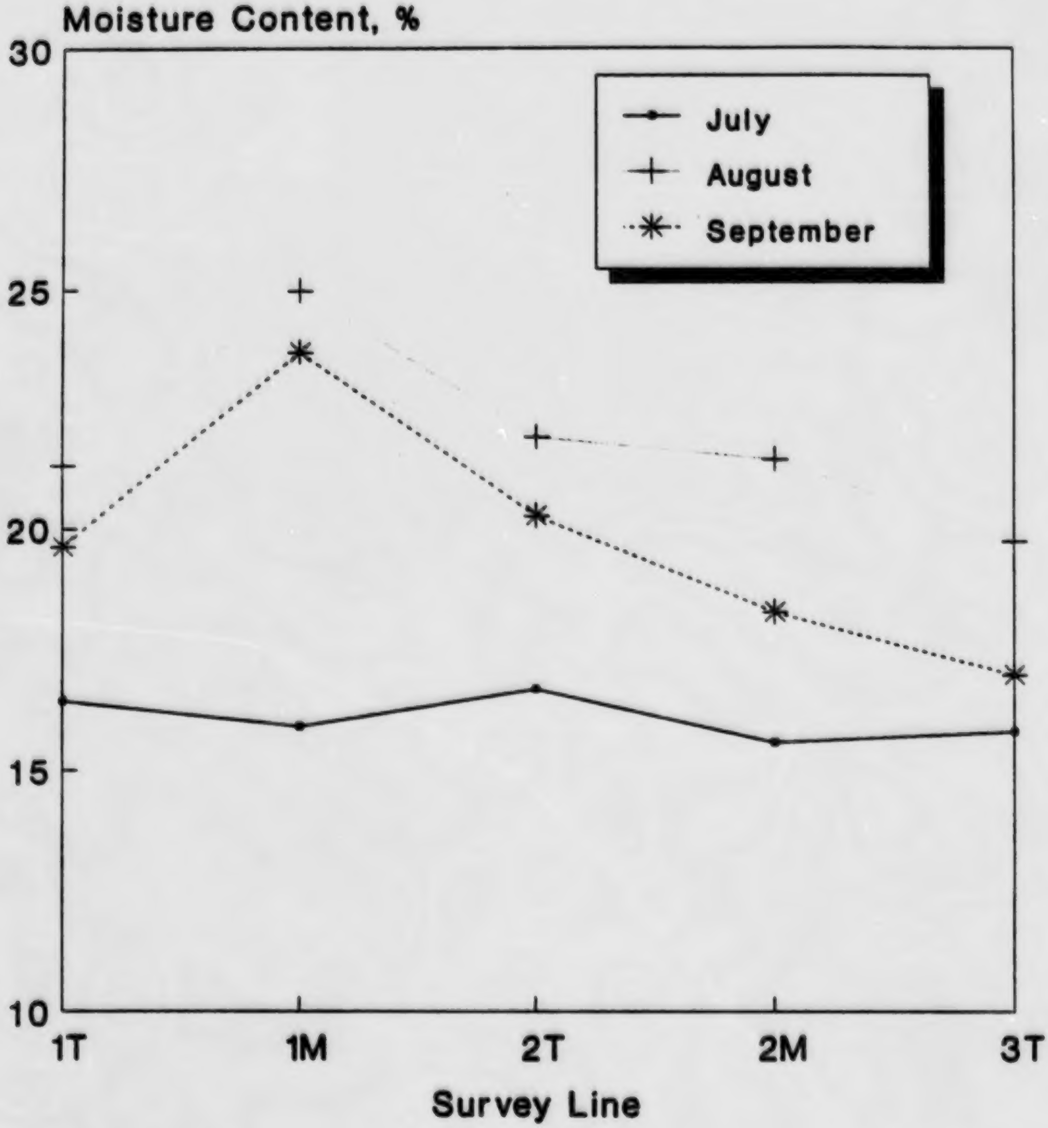
The mean values given in Table 6.2 are averages of all readings taken with the Troxler Nuclear Moisture-Density meter on field visits in July, August, and September, 1989. The results show the average moisture content at the 100mm depth to be higher on all farms than at the 200mm depth. Laboratory determinations of moisture content on soil samples obtained from the field at all sites also show this trend.

Figure 6.1
Moisture Content (Troxler)
along Survey Lines; Farm 1 - 1989



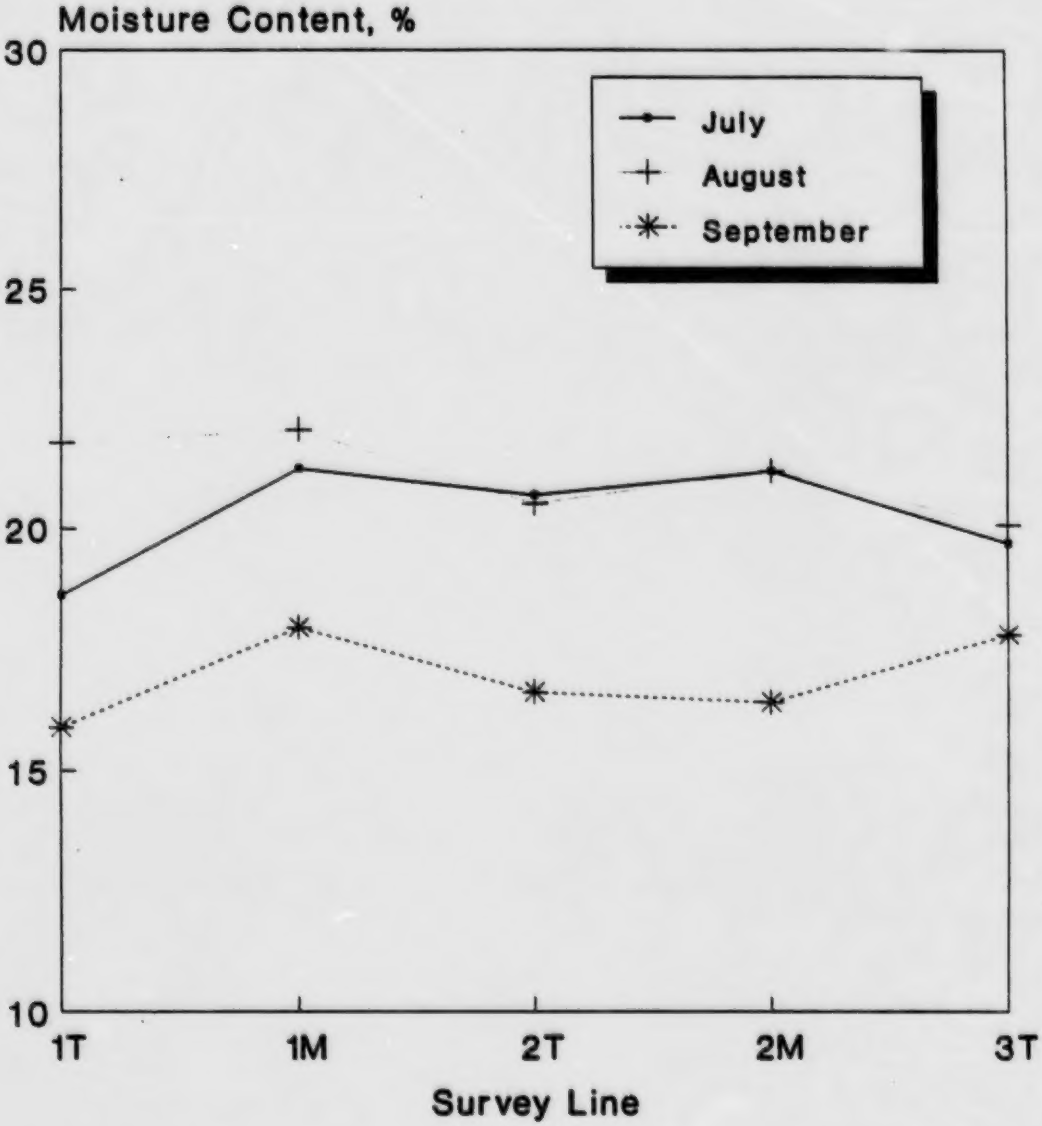
M=Midpoint; T=Tile
Both survey lines combined

Figure 6.2
Moisture Content (Troxler)
along Survey Lines; Farm 2 - 1989



M=Midpoint; T=Tile
Both survey lines combined

Figure 6.3
Moisture Content (Troxler) along Survey Lines; Farm 3 - 1989



M=Midpoint; T=Tile
Both survey lines combined

In 1990, Troxler measured mean moisture content readings on Farm #1 were 15.25% at 100mm and 14.15% at 200mm (combined mean value of 14.70%). These means were calculated from readings taken along Survey Line 3 (S.L. 3) on field visits in April, June, and July of that year.

Moisture Content profiles for Farm #1 along Survey Line 3 in 1990 are shown on Figure 6.4.

6.2.2 Density Measurements

Troxler density measurements for all farms are reported in Table A6.3.

Density Measurements (Troxler) between Survey Lines were compared for each farm. The results are shown in Table 6.3.

On all farms the mean dry density was higher along Survey Line 1 than along Survey Line 2.

Troxler Mean Dry Densities were also compared at the 100mm (4") and 200mm (8") depths with results as given in Table 6.4.

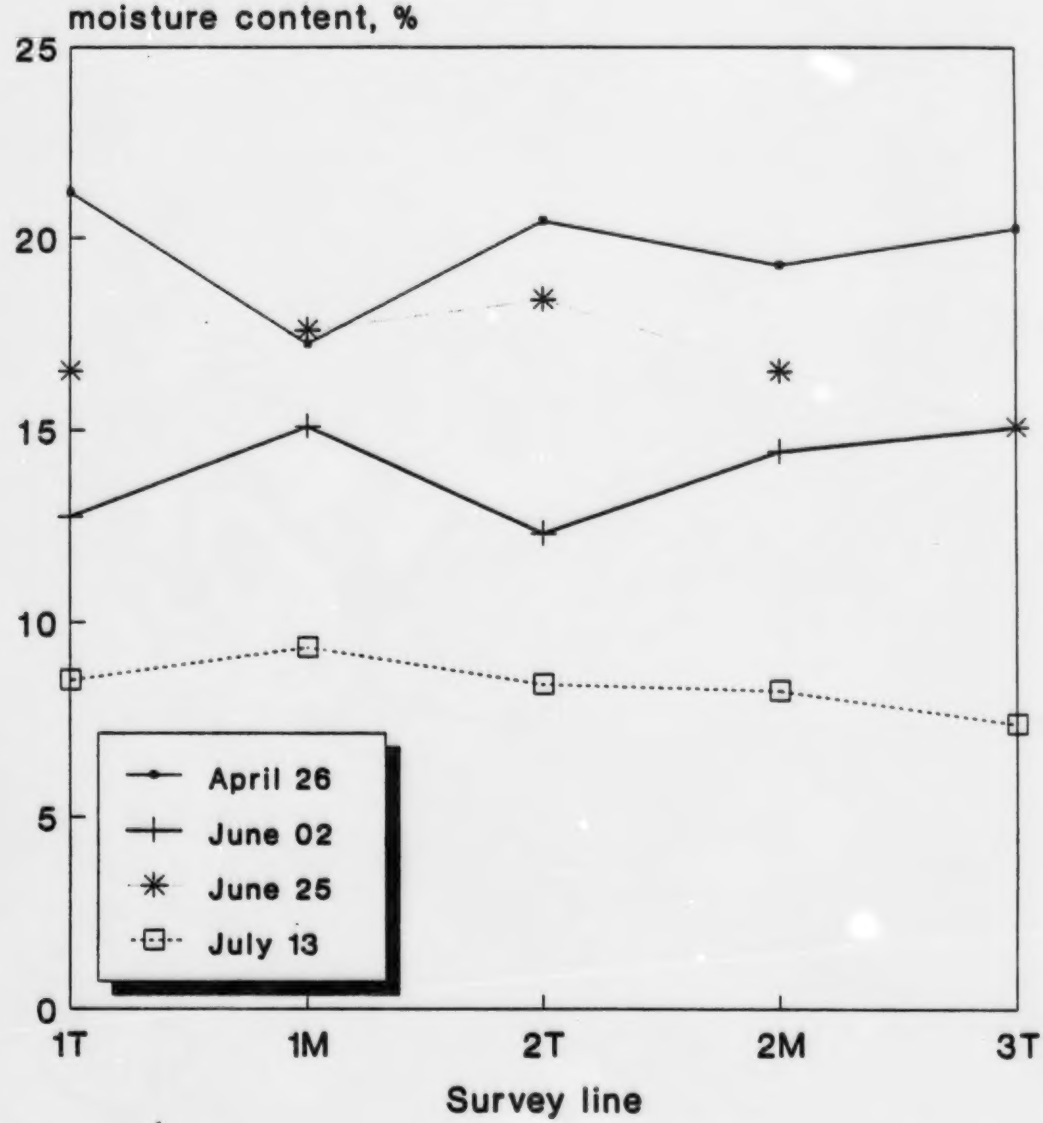
Table 6.3 Mean Dry Density (kg/m^3 x 1000), 1989, by Survey Line

Farm #	SL 1	SL 2	Combined Farm
1	1.45	1.36	1.41
2	1.46	1.45	1.46
3	1.50	1.45	1.48

Table 6.4 Mean Dry Density (kg/m^3 x 1000), 1989, by Depth

	100mm	200mm	Combined Farm
Farm #1	1.36	1.45	1.41
Farm #2	1.42	1.49	1.46
Farm #3	1.43	1.53	1.48

Figure 6.4
Moisture Content (Troxler)
along Survey Line; Farm 1 - 1990



M=Midpoint; T=Tile
One survey line

Dry densities at the 200mm depth are consistently higher on all farms than at the 100mm depth. Dry densities were also highest on Farm #3 at 1480 kg/m^3, and lowest on Farm #1 at 1410kg/m^3.

Troxler measurements of mean dry density in 1990 on Survey Line 3 on Farm #1 yielded values of 1385kg/m^3 and 1475kg/m^3 respectively at the 100mm and 200mm depths. The average for Survey Line 3, based on all readings taken in 1990, was 1430kg/m^3. The field density measurements are given in Table A6.2.

The trend of higher density at the 200mm depth was again borne out by all 1990 measurements. Densities were also measured at non cultivated control points on the various field visits. These non cultivated control points had average dry densities of 1450kg/m^3 at the 100mm depth and 1550 kg/m^3 at the 200mm depth.

Figure 6.5 shows a density profile along Survey Line 3 on Farm #1 representative of density measurements taken in April, June, and July, 1990.

Comparison of density differences over the tile locations and at the mid point between tiles were also made. Averages of Troxler density measurements made in July, August and September 1989 at the tiles and mid points are shown in Table 6.5.

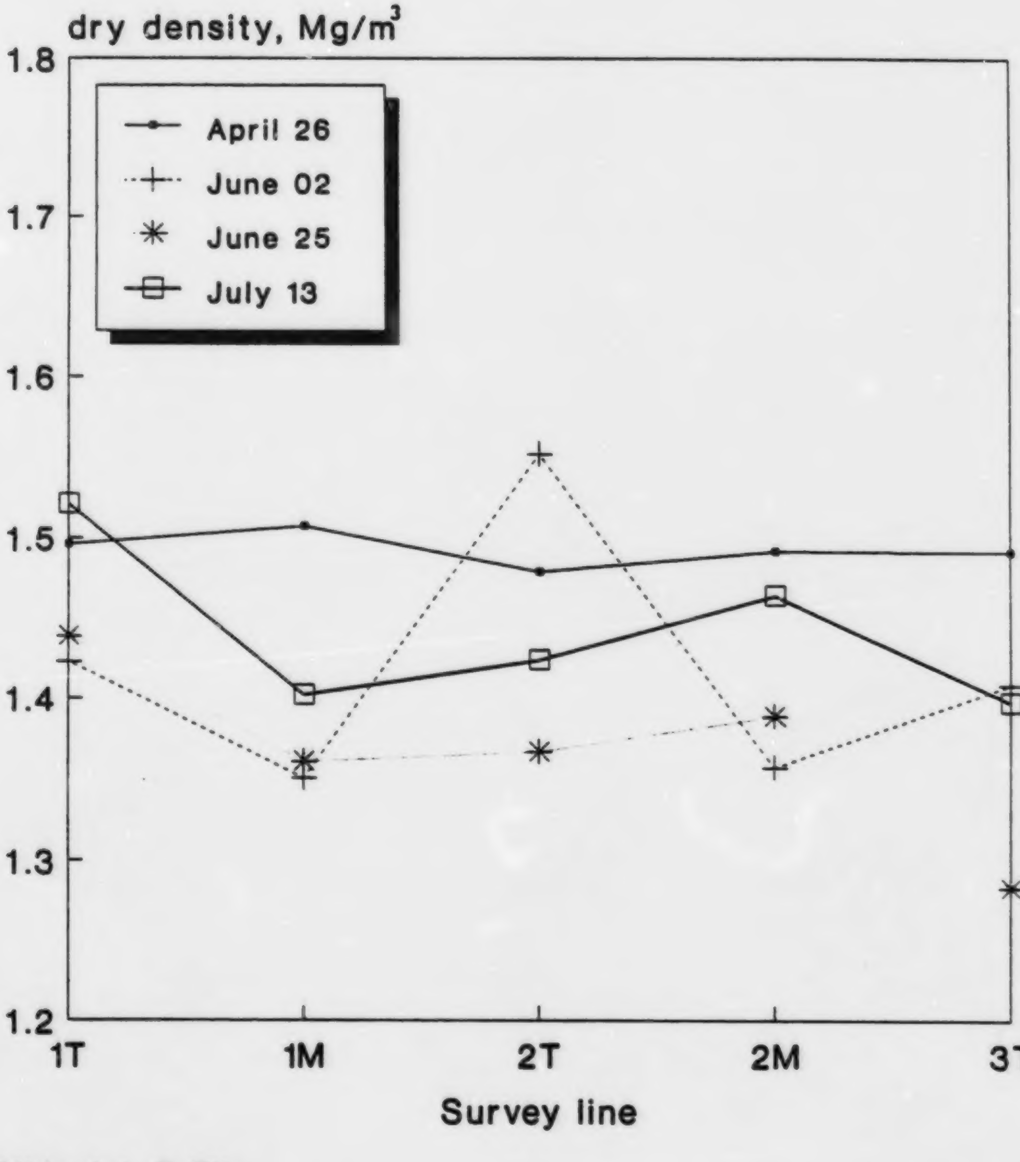
Table 6.5 Mean Dry Density over Tiles and at Mid Points (kg/m^3 x 1000), 1989

	100mm depth Farm #			200mm depth Farm #		
	1	2	3	1	2	3
Over Tile	1.33	1.43	1.45	1.43	1.49	1.54
At Mid point	1.40	1.41	1.43	1.48	1.49	1.51

Farm #1 showed higher density at the mid point between tiles than over the tiles. Farms #2 and #3 either have equal or higher densities over the tiles than at the mid point between tiles. There was therefore no general trend of density measurements over the tile and at the mid point for these farms.

For all farms the average density at 100mm was 1405 kg/m^3 over the tile and 1413 kg/m^3 at the mid point. Correspondingly at 200mm the average densities were 1489 kg/m^3 and 1494 kg/m^3 over tile and at mid point respectively.

Figure 6.5
Dry Density (Troxler)
along Survey Line; Farm 1 - 1990



M=Midpoint; T=Tile
One survey line

6.2.3 Groundwater Levels

Water levels were measured in each piezometer in 1989 on the dates shown below:

Farm #1	July 7, 13, 27, August 17, 31, September 24
Farm #2	July 7, 13, 27, August 18, 31, September 25
Farm #3	August 18, 30, September 24

These dates coincided with those on which in situ Troxler measurements were made of density and moisture, and when bulk soil samples were taken from each site. The piezometer readings indicate that water levels were generally below tile drain invert levels during the period of study.

On 1989 07 27, significant rainfall (50mm to 62.5mm) on the day before and the day of field measurement yielded water level readings in the piezometers at or close to ground level on Farm #1 and #2. No measurements were possible on Farm #3 on that date as piezometer installations were still being completed. On 1989 08 30, measurable water levels were observed on Farm #3 after a total of 37.5mm of rain had fallen on the farm on 1989 08 28 and 1989 08 29. Groundwater levels were found to be between 0.69m and 0.78m below ground surface or at approximately tile invert level.

Results of 1989 piezometric water level observations appear in Table A6.4. Precipitation data reported by farmer cooperators is given in Table A6.5.

Late spring and summer 1990 water levels were measured in the piezometers installed on Farm #1. The results of these observations are given in Table A6.6.

Figure 6.6 is a graphical representation of piezometer water levels in relation to rainfall recorded. Figure 6.7 shows the water level profile at tiles and mid points in the spring of 1990.

6.2.4 Soil Cracking

Visual observations were made of soil cracking which was very evident at all experimental sites. Photographs were taken in typical areas (see Appendix). Little in the way of measurement of soil cracking was carried out in 1989.

Observations on Farm #1 in late April, 1990, showed minimal evidence of soil cracking. Some hairline cracks were present and crack depths of the order of 25-30mm were noted at laboratory determined field moisture contents between 27% and 29%.

In June and July of the same year (1990) crack depths on the same farm varied from a low of 125mm to 450mm+, while crack widths up to 40mm were quite common. This striking crack development occurred at laboratory determined field moisture contents ranging between 12% and 18%.

Figure 6.6
Farm 1: Comparison of Rainfall & Groundwater Elevations 1990

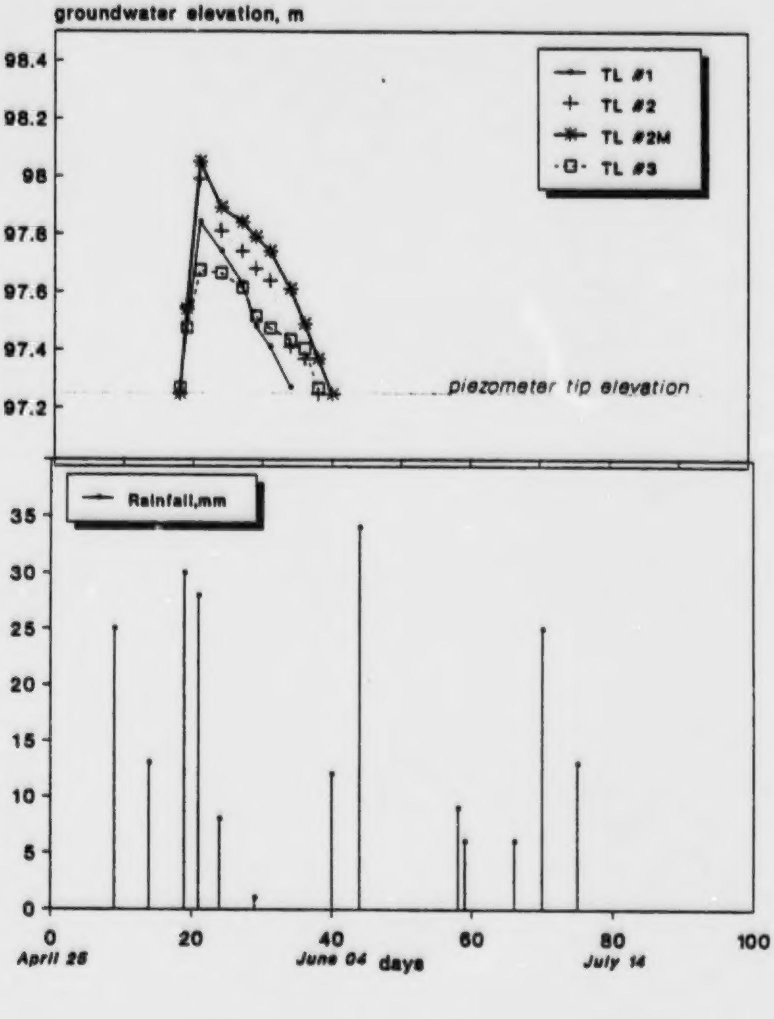
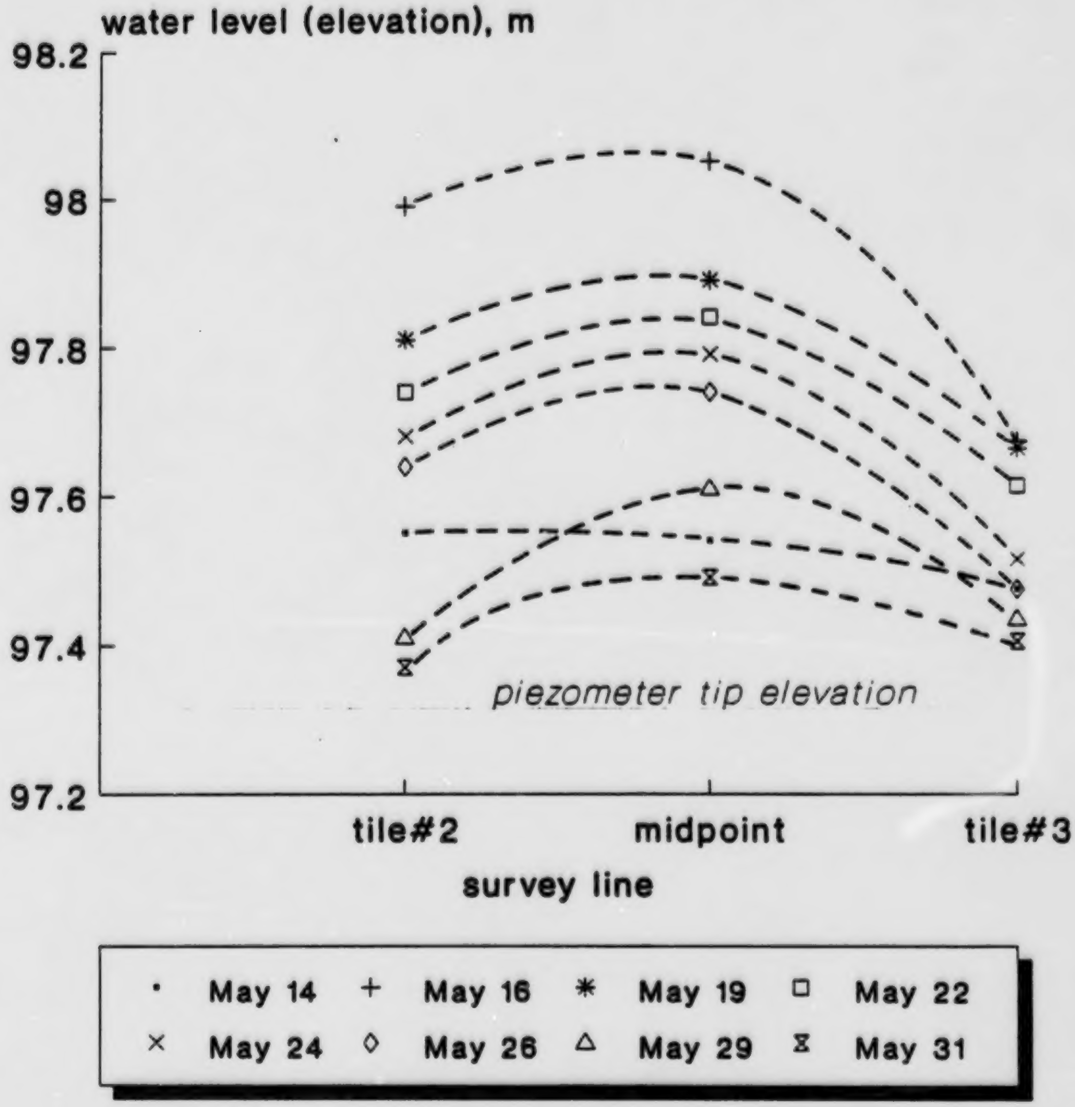


Figure 6.7
Farm 1: Water Levels in Piezometers at tiles and midpoints - 1990



water levels in piezometers
are reduced to an assumed datum

Computations were made of crack volume, as well as other soil characteristics, using data from soil crack tests performed on field visits in April, June, and July, 1990. This information is reported in Table 6.6.

Table 6.6 Moisture Content, Net Soil Air, Soil Physical Characteristics

Sample No.	Month 1990	Moist. Cont. Lab. (%)	Crack Volume (%)	Gross Porosity* (%)
SCT 1	April	28.9	7.7	50.4
SCT 2	April	27.6	12.2	50.2
SCT 3	June	18.5	13.2	46.1
SCT 4	June	18.0	26.1	48.3
SCT 5	July	16.5	27.8	50.9
SCT 6	July	12.1	19.3	47.4

* includes voids in cracks as well as in aggregate pore spaces

Figure 6.8 shows average crack volume and moisture content variation over time for Farm #1 in 1990.

6.2.5 Crop Yields/Plants Heights

Table A6.7 in the Appendix shows the mass of total plant material and grain collected from each experimental area, by Survey Lines. Highest yields were obtained on Farm #1, lowest yields on Farm #3, and intermediate yields on Farm #2. Some grain was lost on Farm #3, Survey Line 2, because of a thresher choke. An adjustment was made to the grain loss by using a Harvest Grain Weight to Plant Mass Index. This Index varied between 0.375 and 0.40 for all Survey Lines, except Survey Line 2 on Farm #3 which, because of the lost grain, was 0.27. Using an average Index value of 0.38, the grain mass for the Survey Line with lost grain was adjusted upwards to a grain mass at harvest of 8971g, with a corresponding laboratory mass of 7579g at 13.1% moisture content, and 8100g at 14% moisture content.

Table A6.8 in the Appendix summarizes the measured plant heights recorded during the course of this study.

6.2.6 Tensiometers

Tensiometer readings from Farm #1 in 1990 are reported in Table A6.6 in the Appendix. Figures 6.9 and 6.10 show Tensiometer readings at the 200mm and 300mm depths in relation to rainfall recorded and at locations adjacent to and at the midpoint of the drain laterals.

Figure 6.8
1990: Time Variation of Farm Average Crack Volume and Moisture Content(Lab)

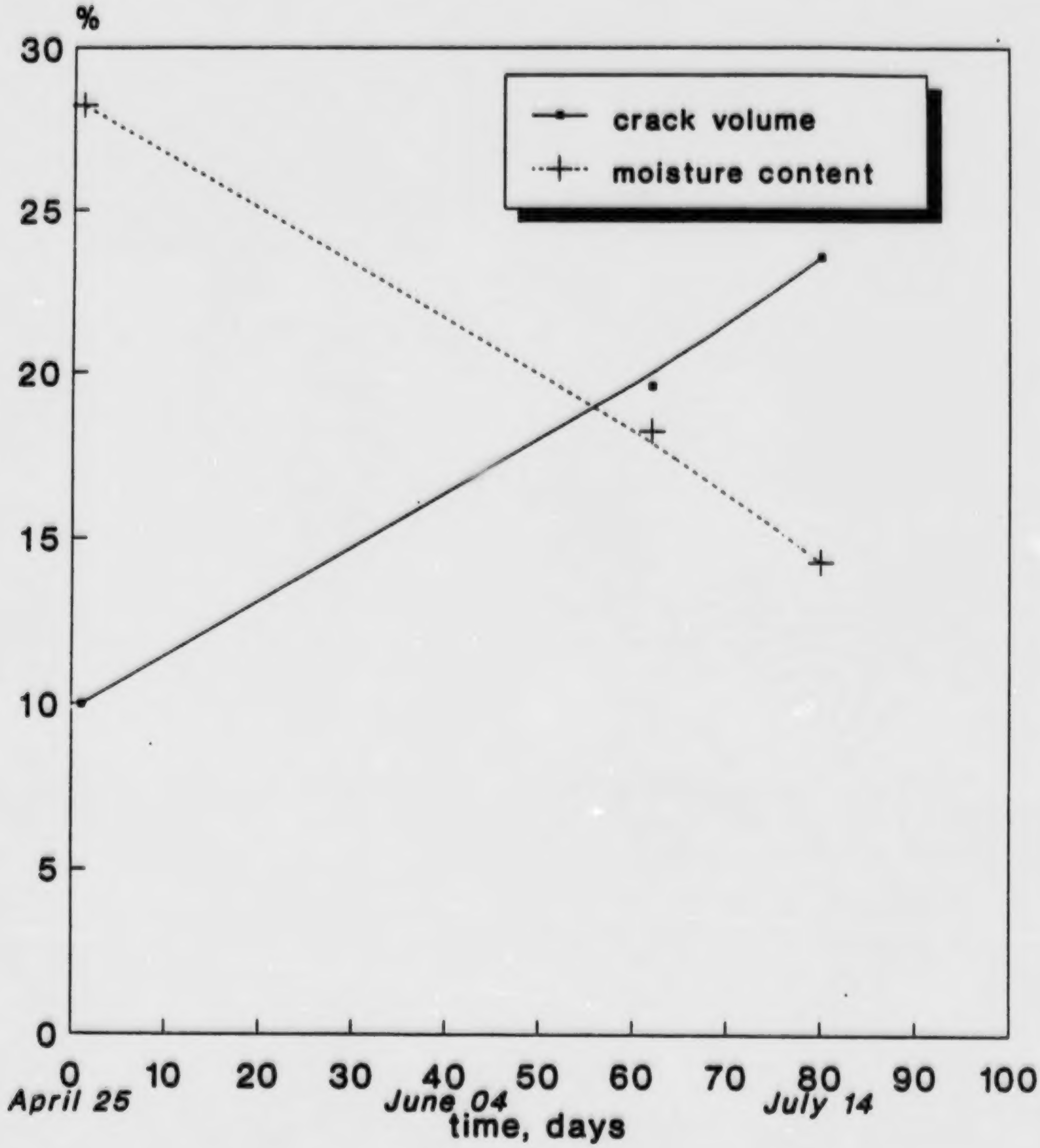


Figure 6.9

Farm 1: Comparison of Soil Tension and Rainfall at Tile Location - 1990

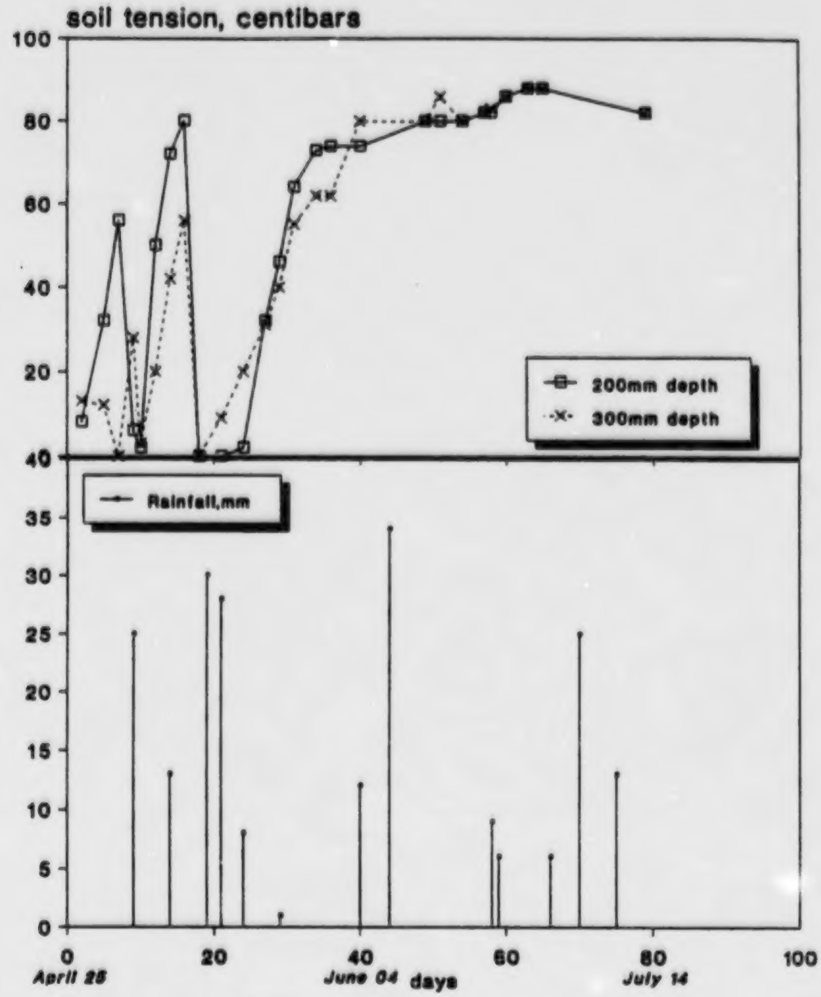
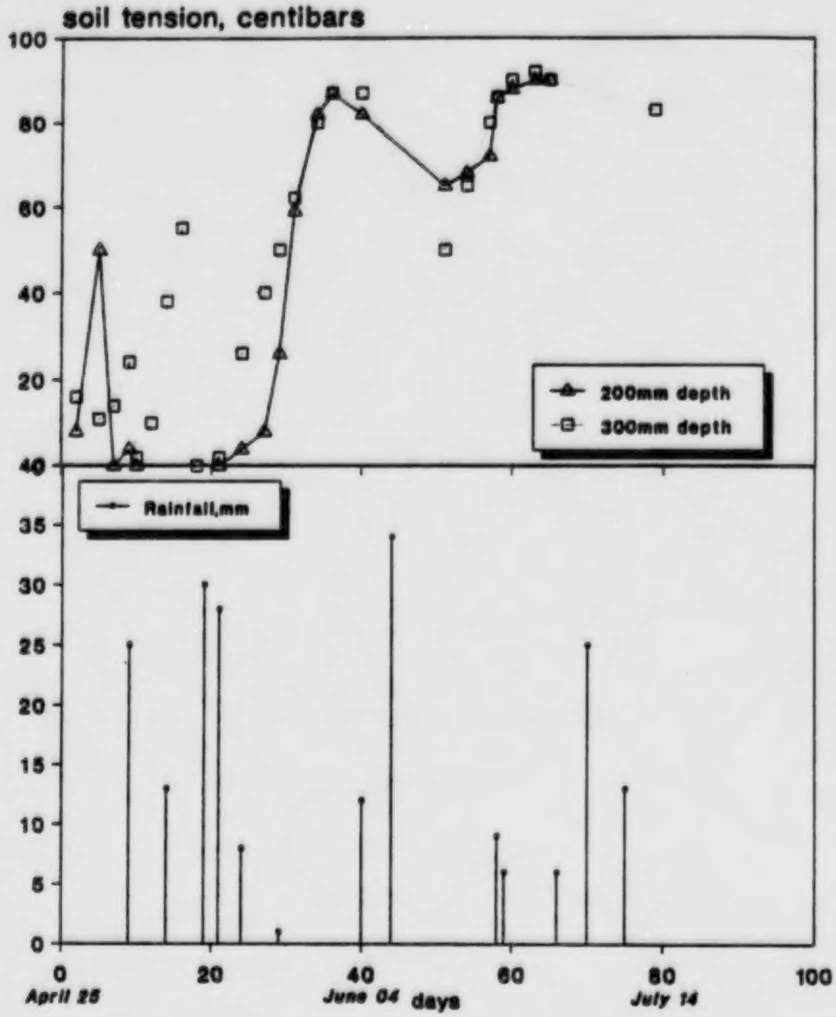


Figure 6.10

Farm 1: Comparison of Soil Tension and Rainfall at Midpoint between Tiles -1990



6.2.7 Hydraulic Conductivity

The hydraulic conductivity value obtained from the measurements made on Farm #1 in August, 1989, was 1.78 x 10^{-4}m/sec. This value was obtained by assuming log-normal distribution of hydraulic conductivity measurements at four locations with a standard deviation of 2.93.

On Farm #3, in July 1990, Guelph Permeameter measurements yielded an average hydraulic conductivity value of 2.78 x 10^{-4}m/sec.

A computation of hydraulic conductivity on Farm #1 was made using water level data from the four piezometers installed on this farm in the spring of 1990. The Hvorslev (1949) slug test method was used to calculate the hydraulic conductivity. The average value obtained under these more saturated soil conditions was 8.8 x 10^{-9}m/sec.

6.3 Laboratory Tests

6.3.1 Moisture, Density, Shrinkage

Moisture content, density, and soil shrinkage results of field bulk samples tested in the laboratory in 1989 are given in Table A6.9 in the Appendix. Troxler and laboratory determined values for moisture and density are given in Table A6.10.

Similarly, shrinkage data for 1990 measurements on Farm #1, appear in Table A6.11.

6.3.2 Densities and Compaction

The soil Atterberg limits are shown in Table A6.12 and Fig. A6.1 in the Appendix. Density and specific gravity information appear in Table A6.13. Laboratory Proctor density test results are given in Table A6.14. It will be noted that the optimum moisture content is very close to the plastic limit of the soil, an observation well known in soil mechanics for most clay type soils.

6.3.3 Root Growth

The results of measurement of root characteristics of randomly selected healthy plant specimens on each site are reported in Table 6.7.

6.3.4 Harvest Yields

Table A6.7 in the Appendix shows grain yields in kg/ha adjusted to 14% moisture content based on grain mass and moisture contents provided by Harrow Research Station.

The average farm yields are given in Table 6.8.

Table 6.7 Root Measurements, 1989.

Farm No.	Maximum Root Diameter (mm)	Root Length (mm)	Penetration Depth (mm)
1	6.9	112	96
2	5.9	117	108
3	6.1	103	96

Note: Measurements reported above are mean values from four plant specimens (two along each survey line) on each farm. Penetration depth is the vertical projection from ground surface level to the tip of the main plant root.

Table 6.8 Average Farm Yields

Farm No.	Yield (kg/ha)	Remarks
1	3545	
2	2820	
3	1355 1625	(unadjusted) (adjusted for loss)

6.3.5 Soil Cracking

The photographs in the Appendix show development of soil cracking as simulated under laboratory conditions. The crack patterns are very similar to those observed in the field, and of a similar size in plan.

These laboratory experiments were not a part of this research study, but were attempted nonetheless for future possible studies into soil cracking. In-house research work will be continued, using student surplus help, as and when available to the Firm.

7.0 DISCUSSION OF RESULTS

7.1 Study Approach

A number of relationships between interacting variables are developed for discussion purposes. Comments are also made on drainage effectiveness on the three sites and on the reliability of Troxler nuclear measurements of soil moisture and density by in situ techniques.

It should be recognized that the relationships discussed below are based on regression analyses from field observations and laboratory tests. In some cases, the number of data points is so low that any inference as to validity of the conclusions indicated in this report must be tempered accordingly. Wherever possible, the discussion reflects this limitation.

7.2 Relationships

7.2.1 Moisture Density-Compaction

Table 7.1 shows the average optimum moisture contents obtained from the Proctor tests.

Table 7.1 Average Optimum Moisture Contents (%)*

Farm No.	Standard Proctor (25 blows)	"Modified" Proctor (10 blows)
1	20.1	22.1
3	19.3	20.5
Composite	18.5	20.0

* Obtained from Proctor Tests

The moisture-density relationship is given for most soils by a parabolic curve (convex side up), indicating increasing density with increasing moisture content to a maximum value for that particular soil and for the particular energy of compaction used. By definition, the optimum moisture content is that moisture content at which the particular soil achieves its maximum density under a given energy of compactive effort. As compaction energy increases, the optimum moisture content decreases, while the dry density increases. Thus, the parabolic curve moves upwards and to the left of the moisture (x-axis) vs. dry density (y-axis) plot with increasing energy of compaction.

The results of Table 7.1 show the optimum moisture content of the Brookston soil to be about 20%. The number of blows (25 or 10) applied with a standard 2.5kg hammer reflects the energy levels used in compacting the soil.

In the above case, a "Modified"[1] compaction energy (10 blows applied to each of 3 layers, with a 2.5kg hammer freely falling 305mm), lower than that used in the Standard Proctor Test (25 blows per layer), has also been applied, since farm equipment induced compaction energy levels are felt to be much lower than those used in civil construction works.

Figure 7.1 shows dry density vs. moisture content for the Troxler field measurements. Superimposed on this figure are moisture-density plots from Proctor Density tests [both Standard Proctor (25 blows) and "Modified" Proctor (10 blows)].

Figure 7.2 is a similar plot of dry density versus moisture content for laboratory determined measurements.

Both Figures 7.1 and 7.2 show the differences in soil density between the three farms. The highest density on Farm #3 is however lower than the densities obtained by the "Modified" Proctor Test.

Figure 7.3 is a plot of Dry Density vs. Moisture Content for the 1990 data on Farm #1.

The lower optimum moisture content for Farm #3, coupled with heavier pre- and post-planting agricultural traffic, might account for the higher soil densities observed on this farm. Whether this higher density is of consequence in relationship to crop growth is open to question.

Figure 7.4 indicates the relationship between moisture content (laboratory determined on field bulk samples) and volumetric shrinkage. A new (as yet unpublished) technique was developed in the laboratory for this measurement. It involves an iterative process in the calculation, best performed using a computer program. The technique offers the advantage of measuring the relevant properties on the same soil specimen, thus eliminating the necessity of making measurements on duplicate soil samples, which introduces a considerable error due to inherent differences between soil samples.

7.2.2 Yields-Density-Compaction, Variety

Figure 7.5 shows the relationship between crop yield and mean dry density for all farms.

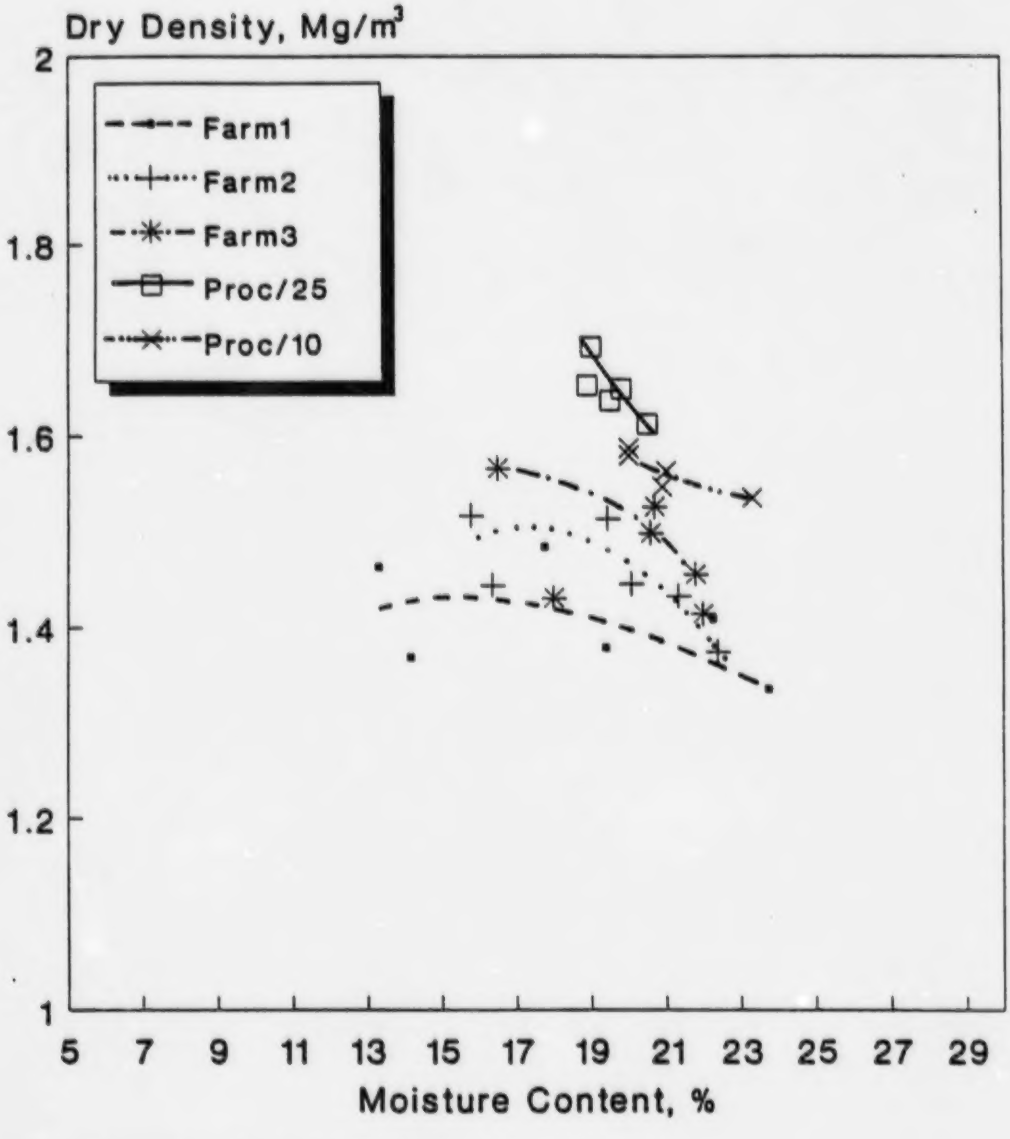
The highest grain yield was observed on Farm #1. The lowest yield was observed on Farm #3. Farm #2 had a yield which, while not as high as for Farm #1, was still nearly double that of Farm #3.

Farm #3 was planted with soy bean variety Pioneer 9202 which reportedly has not performed well under wet conditions. Farm #1 had a mixture of Pioneer 9202 and NK S2424. Farm #2 was planted with variety Corsoy. The average yield from Farm #3 was 1355kg/ha unadjusted (1625kg/ha adjusted) as compared with 2820kg/ha for Farm #2 and 3545kg/ha for Farm #1.

---

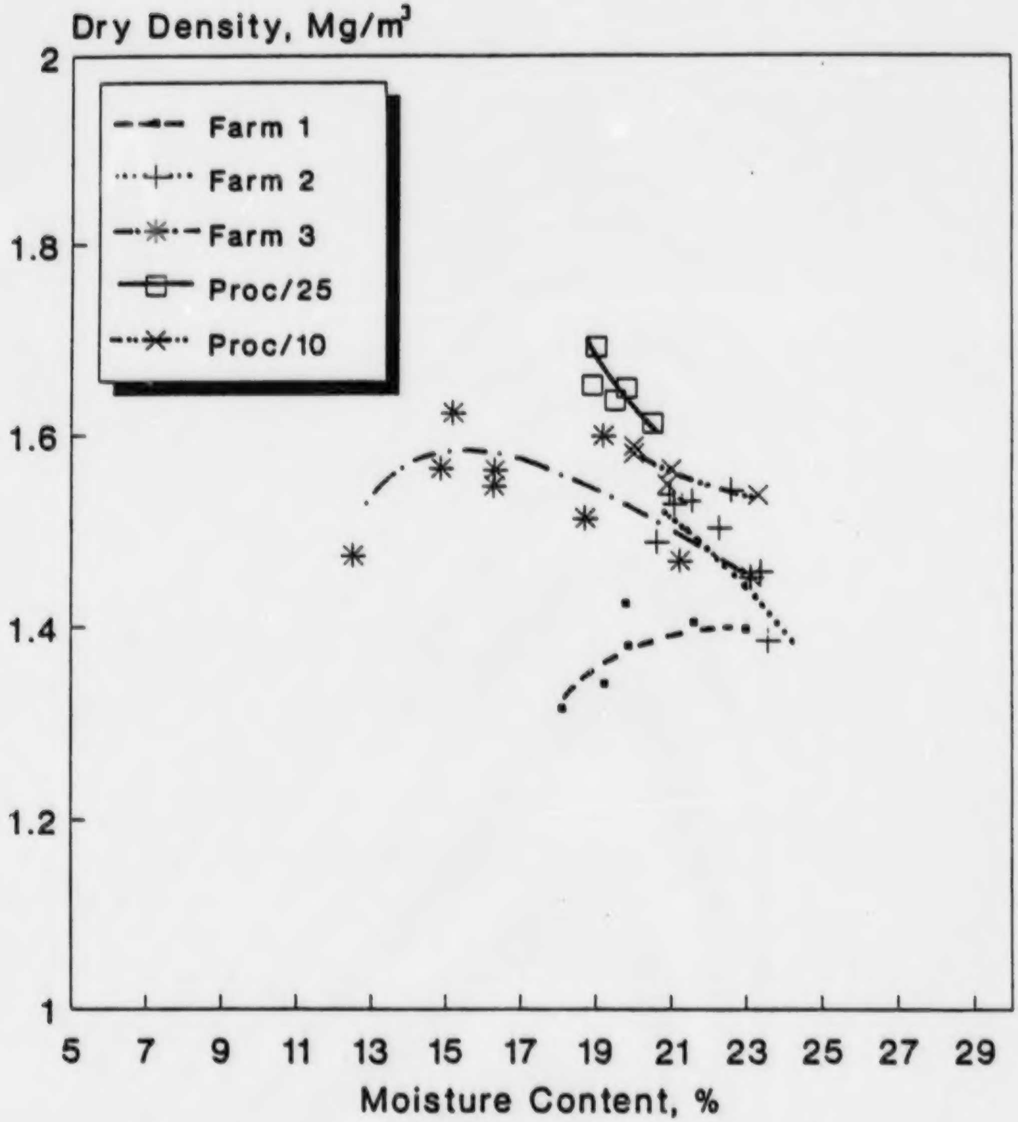
1 Not to be confused with Modified Proctor as per ASTM D 1557 which uses a 4.5kg hammer with 25 blows for each of 5 layers, with hammer free fall of 457mm.

Figure 7.1
Dry Density vs Moisture Content
Troxler - 1989



Mean values by depth and time
Proc=Proctor(10 & 25 blows)

Figure 7.2
Dry Density vs Moisture Content
Laboratory - 1989



Mean values by depth and time
Proc=Proctor(10 & 25 blows)

Figure 7.3
Farm I: Laboratory 1990
Dry Density vs Moisture Content

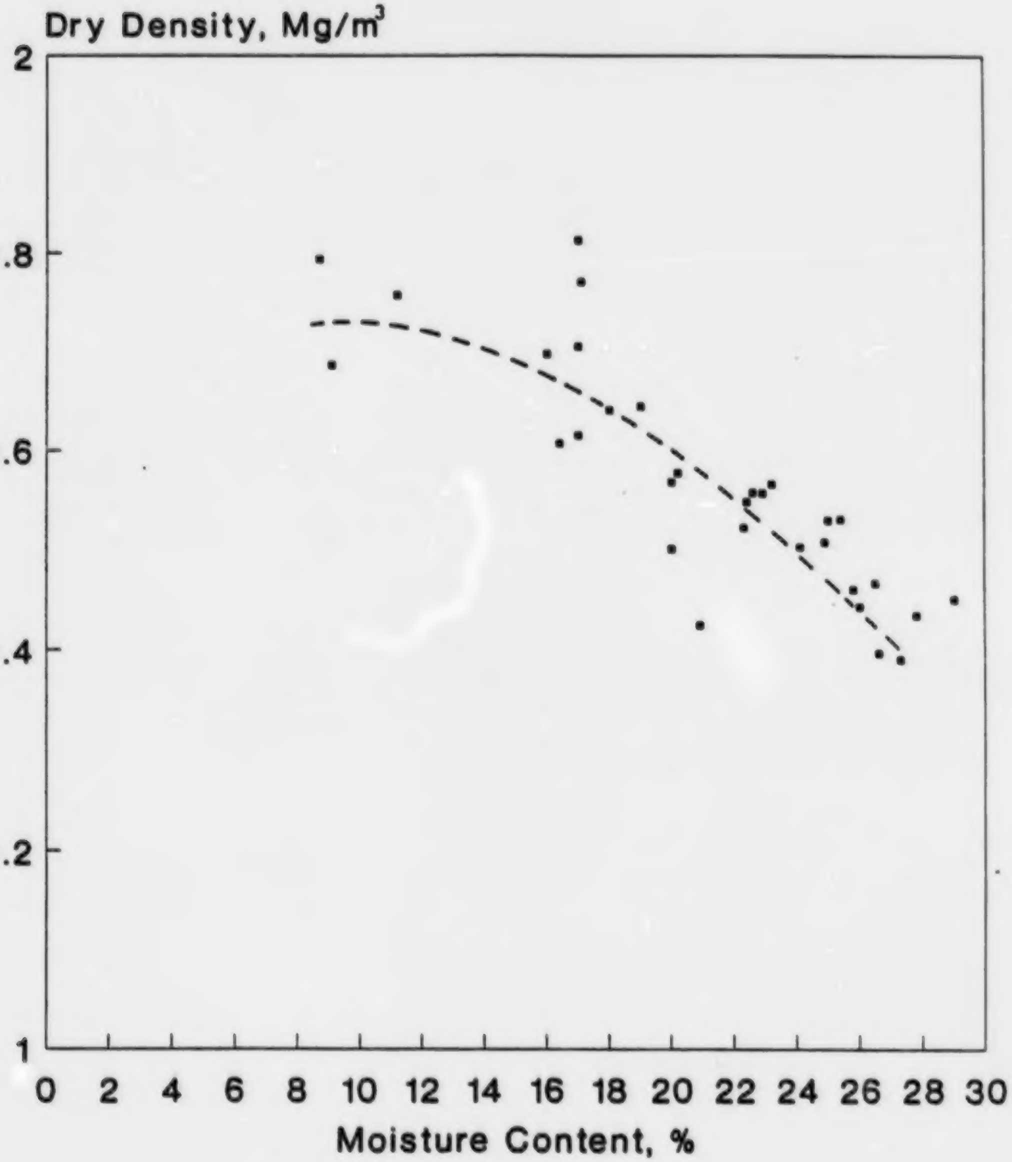


Figure 7.4
Shrinkage vs Moisture Content-Laboratory
1989(all farms) & 1990(farm1)

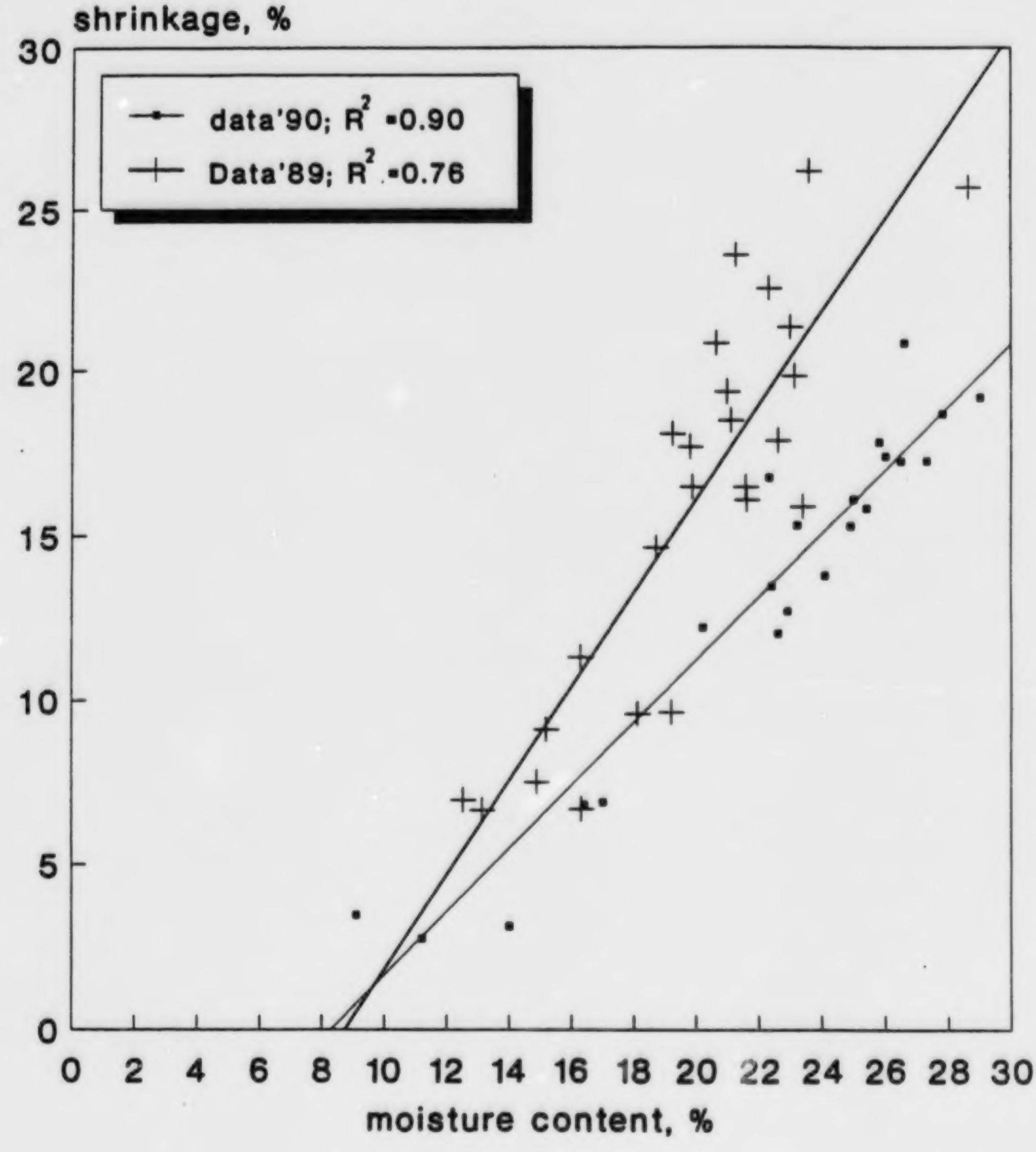
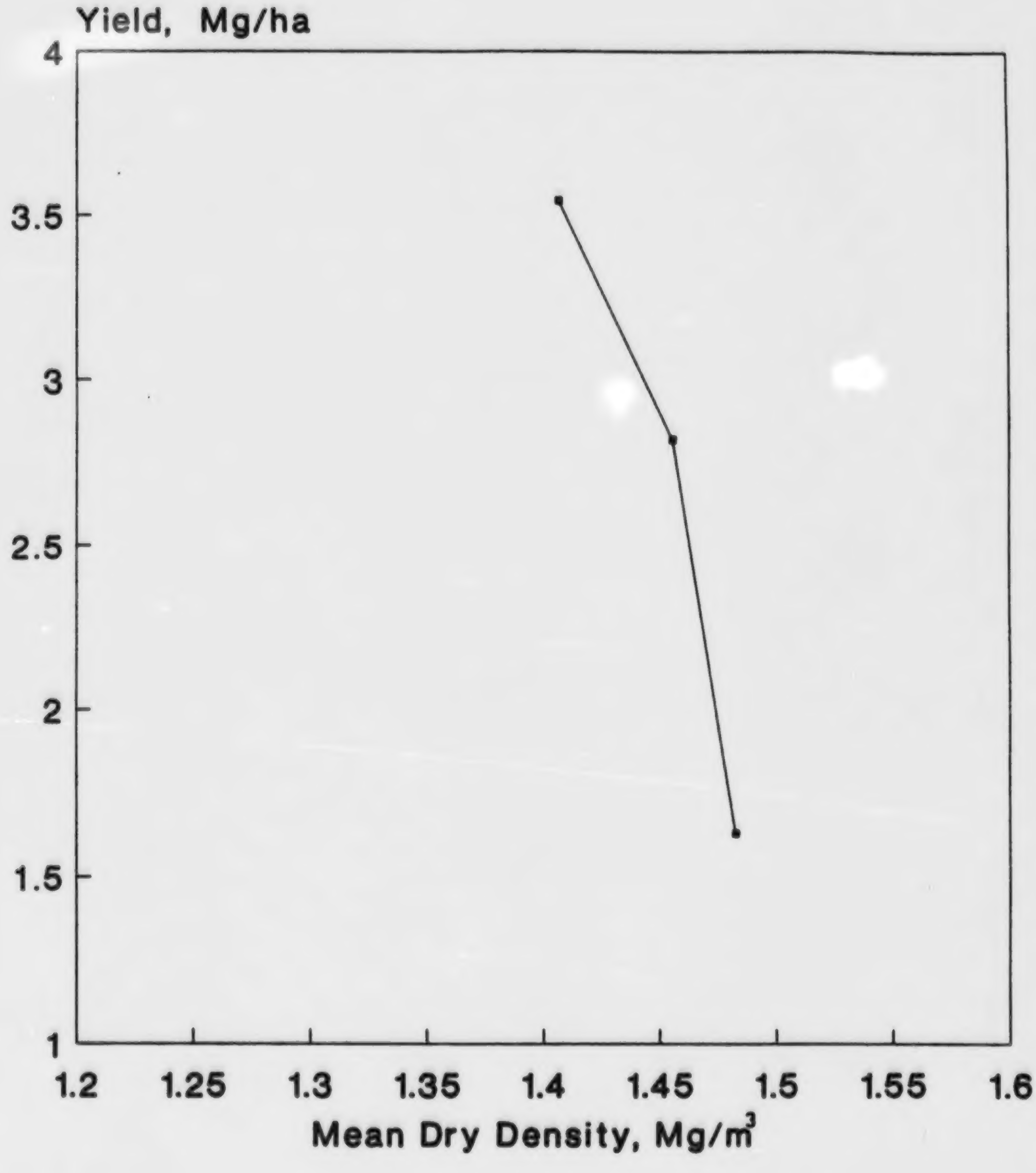


Figure 7.5
Yield vs Mean Dry Density
Farms 1, 2, 3



In order to eliminate the effect of variety, a direct comparison was made between the yield from Survey Line 2 on Farm #1 (which was planted in Pioneer 9202) and the yield from Farm #3, Survey Line 1 and Survey Line 2 (which was planted to the same variety). The results are shown in Table 7.2.

With the same variety planted, the yield from Farm #1 is approximately double that of Farm #3.

The overall commercial field yields reported by the farmer cooperators were as given in Table 7.3.

Table 7.2 Yield Comparisons - Pioneer 9202 Soy Bean Variety

Farm No.	Survey Line	Yield kg/ha	Remarks
1	2	3200	
3	2	1330	unadjusted
	2	1870	adjusted
3	1,2	1355	unadjusted
	1,2	1625	adjusted

Table 7.3 Commercial Yields

Farm No.	Yield Bushels	Yield (kg/ha)
1	50	3290
2	36	2370
3	23	1515

An independent agronomic inspection report prepared just before harvest in 1989 indicated that the Pioneer 9202 crop on Farm #3 was clear of pests, disease, and weeds. However, the crop appeared to have suffered considerable water damage making the plants short, stunted and podded very low to the ground.

Visual observations at Farm #1 also indicated that the Pioneer variety was shorter and more stunted than NK S2424 with which it shared the field.

It appears that even allowing for variations in rainfall, management, and cultivation practices, the difference in yield between Pioneer 9202 on Farm #1 and Farm #3 is considerable and significant.

It may be that the large differences in measured yield of this variety at the two experimental locations is a direct result of the efficiency of the respective drainage systems. Less water damage occurred on the farm with the narrower lateral spacing (Farm 1). This statement is made without the benefit of observation of the moisture regime during and immediately after seeding in late May, 1989. In addition, record rainfall was received in Essex County in July, 1989.

In such a wet growing season it would be expected that better results would be obtained from a heavily drained farm.

7.2.3 Yields - Tile Spacing, Plant Height

Figure 7.6 shows Farm Yields and Tile Spacing. The best yield was obtained on the farm with the least lateral spacing (Farm #1).

Tile spacing and mean plant height at harvest are shown on Figure 7.7. The decrease in plant height with the increase in tile spacing may be the result of the more heavily drained farms having better soil water characteristics, resulting in taller, more vigorous, and better yielding plants, even after allowing for varietal, cultivation, and crop management differences.

7.2.4 Yields - Cropping History/Cultivation/Plant Height

From the limited observations made on this project there appears to be no reduction in yield with intensive cropping (tomatoes) in the rotation. In fact, the highest yields were obtained on the farm with the most intensive treatment. It should be noted also that post planting cultivation on both Farms #1 and #2 was virtually nil.

Both pre- and post-planting cultivation on Farm #3 was greater than on Farms #1 and #2. Soil densities on this farm were found to be marginally higher than on the others but this may not be significant in crop development.

7.2.5 Moisture - Precipitation - Water Levels

The rainfall data collected by farmer cooperators in 1989 must be considered somewhat unreliable based on observations made by Strata personnel. In addition, the infrequent readings of piezometric water levels did not allow appropriate conclusions to be made about water table levels and the efficiency of the drainage systems on the three farms.

It was not possible therefore to arrive at any meaningful relationships with these variables in that year.

Figure 7.6
Yield vs Tile Spacing
Farms 1, 2, 3

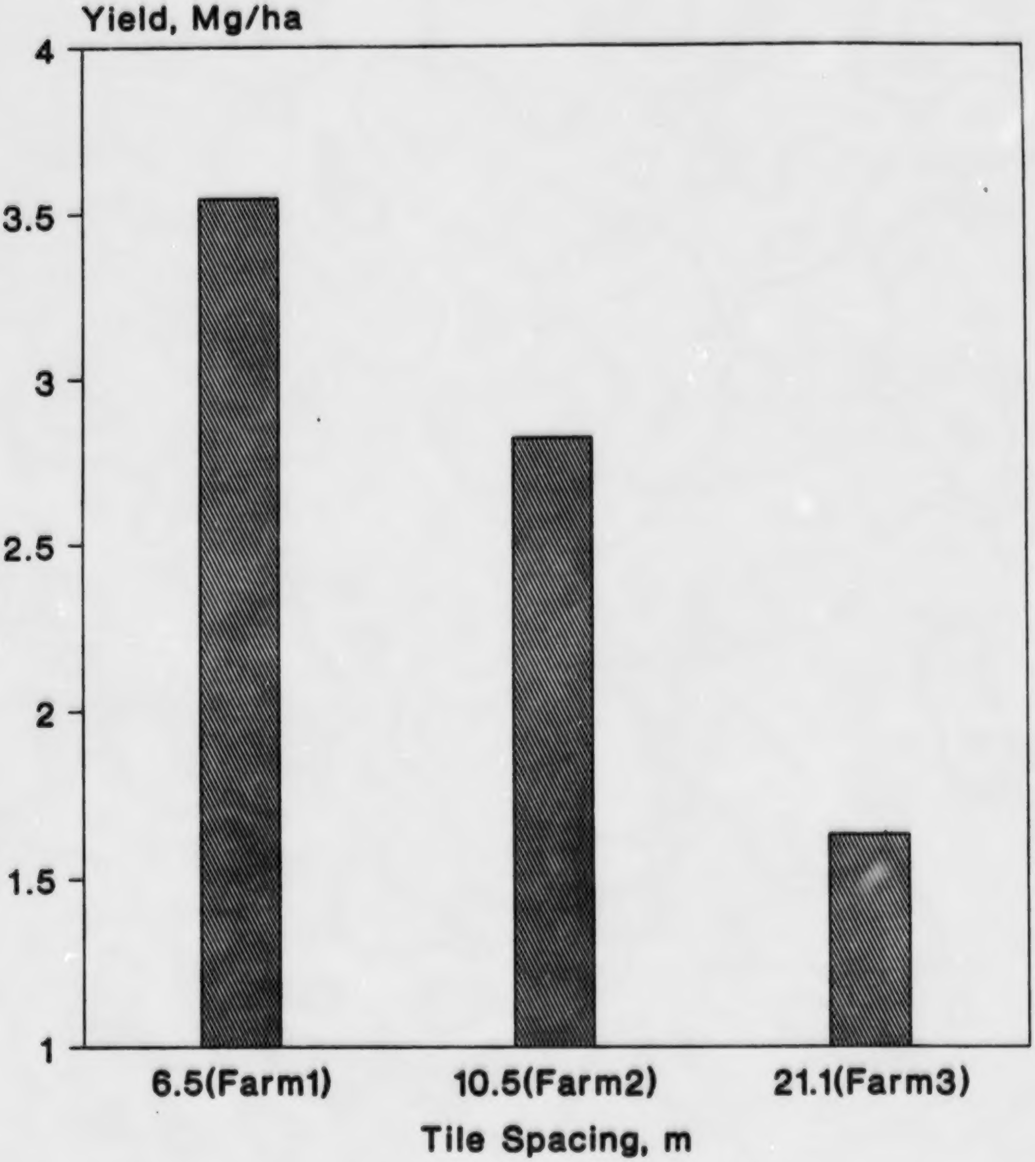
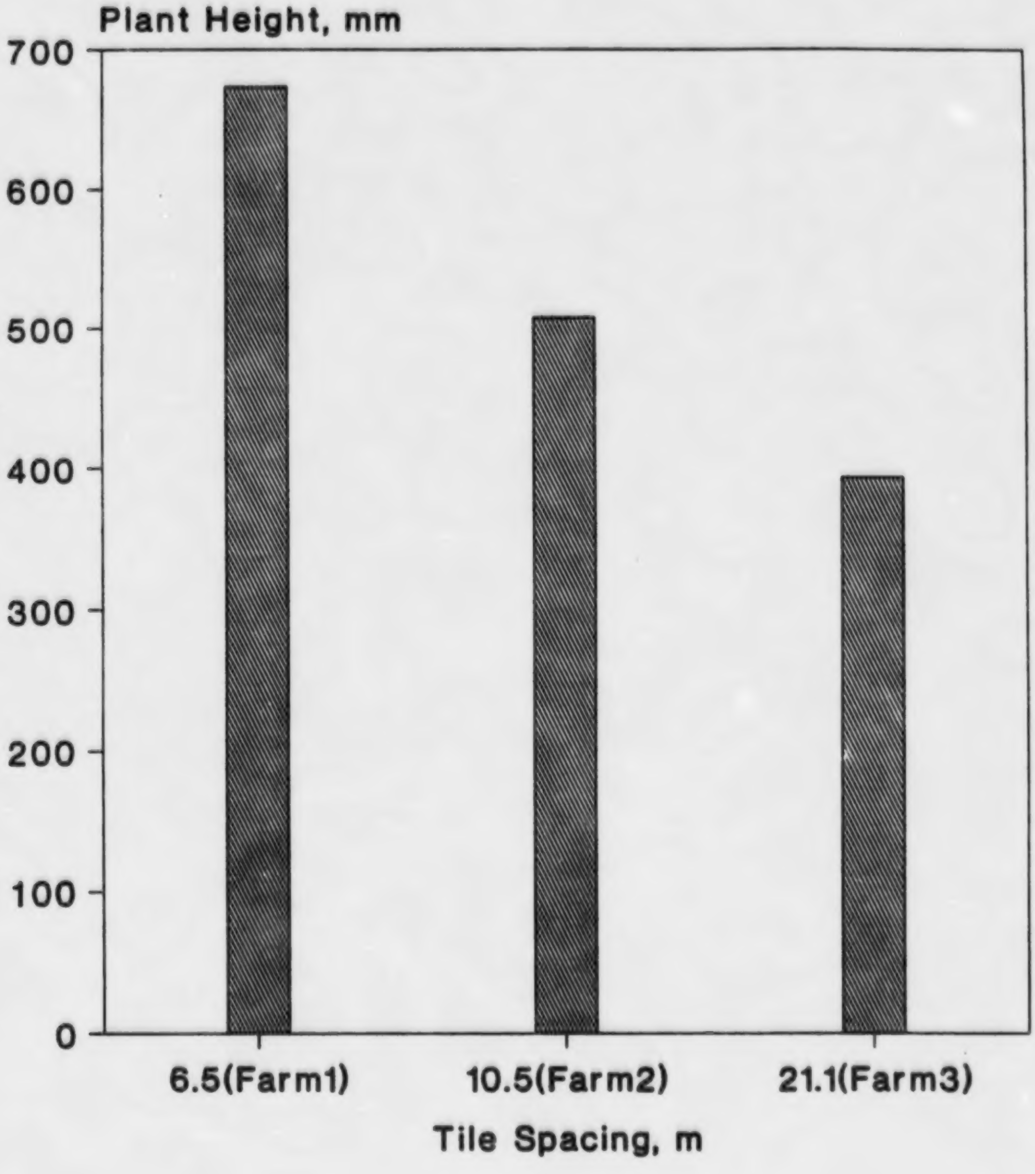


Figure 7.7
Plant Height vs Tile Spacing
Farms 1, 2, 3



In 1990, water levels above tile drain elevations were only measurable in late spring. As seen from Figure 6.7, rainfall in early June, 1990, of as much as 35mm, was insufficient to raise the groundwater levels above the tile drain invert levels. In fact, the water table remained below the drain inverts up to the end of experimentation in mid-July, 1990, when all piezometers had to be removed to allow harvesting of the crop.

7.2.6 Root Growth Measurements

The root growth measurements reported in Table 6.5 were not used to infer any relationships with other parameters.

Major root development appeared to be concentrated in the top 125mm of soil in all cases. It was considered that larger numbers of plant specimens would have to be measured in order to produce data which would be meaningful. This time consuming option was discarded in favour of the measurement of other variables such as crop yield and plant height.

7.2.7 Troxler Data Reliability

The Troxler nuclear meter was extensively used to obtain field measurements of density and moisture content on all sites.

The Troxler readings were compared with laboratory determined moisture contents and densities of samples taken from the same location and nominal depth.

The data from field observations and laboratory tests are shown in Figures 7.8, 7.9 and 7.10.

The following trends are worthy of note:

1. Laboratory determined densities are generally higher than those measured with the Troxler Unit (Figures 7.8 and 7.10);

2. Laboratory determined moisture contents are also generally higher than Troxler values (Figures 7.9 and 7.10);

3. At Farm #1, the Troxler moisture contents on uncultivated control areas are generally closer in value to laboratory determined moisture contents than to those on cultivated farm land (Figure 7.9);

4. Troxler measured dry density in the spring seems to be more representative of laboratory determined densities than those measured in the summer (Figure 7.8);

5. Despite variations from laboratory determined values, Troxler measurements show similar trends and are therefore representative of relative changes in measured values. Figures 7.1 and 7.2 show moisture-density data (both Troxler and laboratory determined) for all Farms, and illustrate this conclusion.

Figure 7.8

Farm 1: Dry Density
Laboratory vs Troxler - 1990

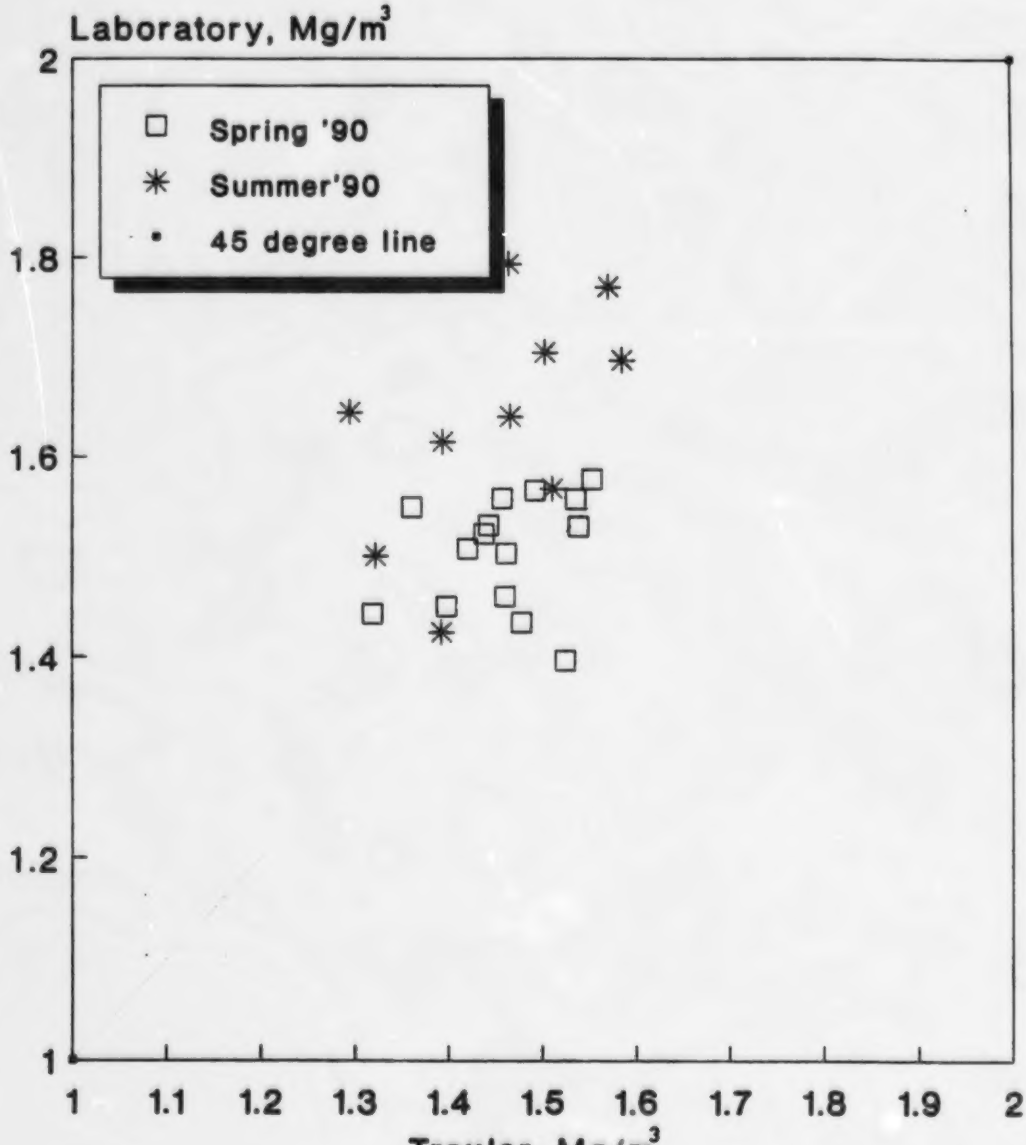


Figure 7.9
Farm 1: Moisture Content
Laboratory vs Troxler - 1990

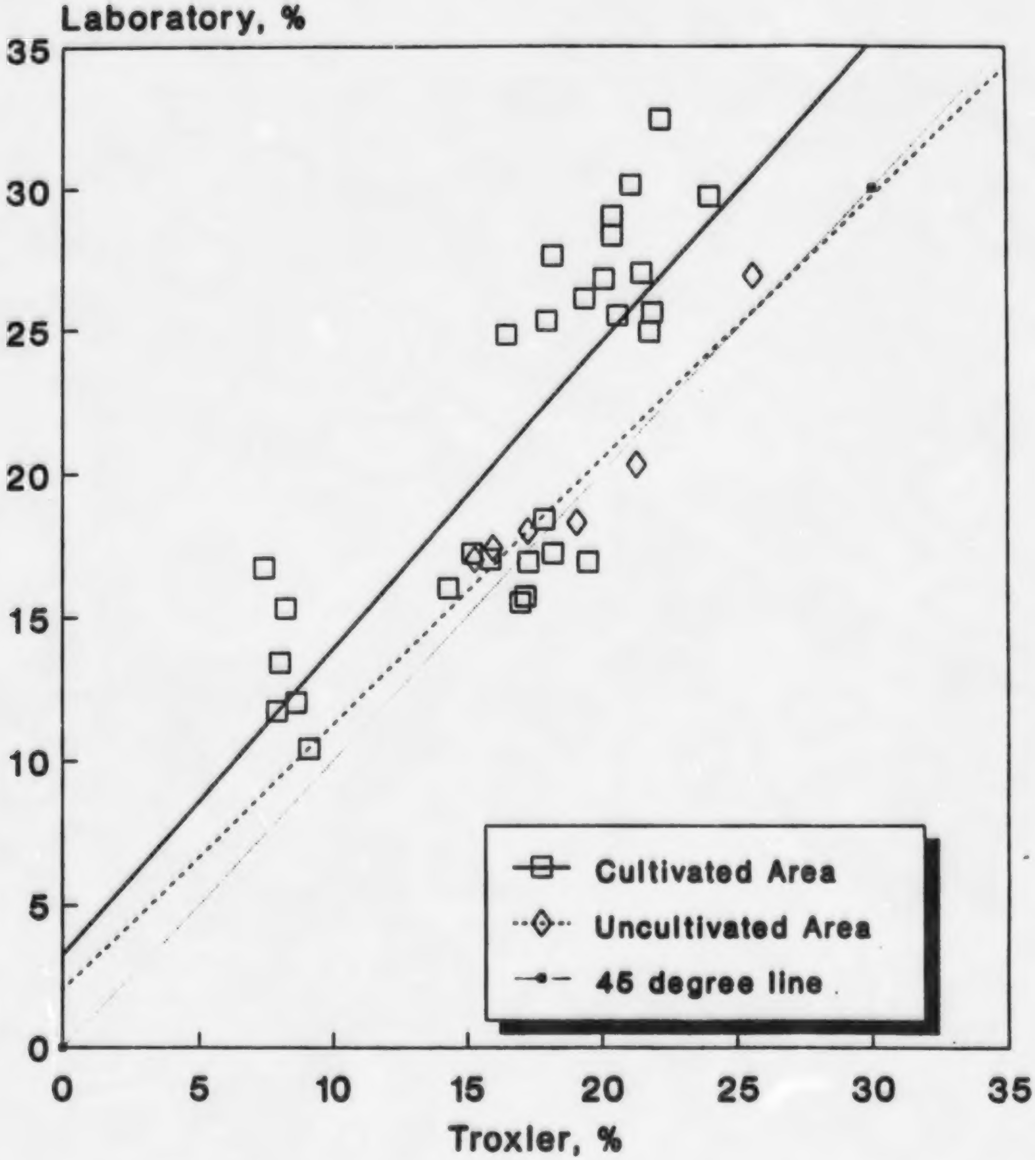
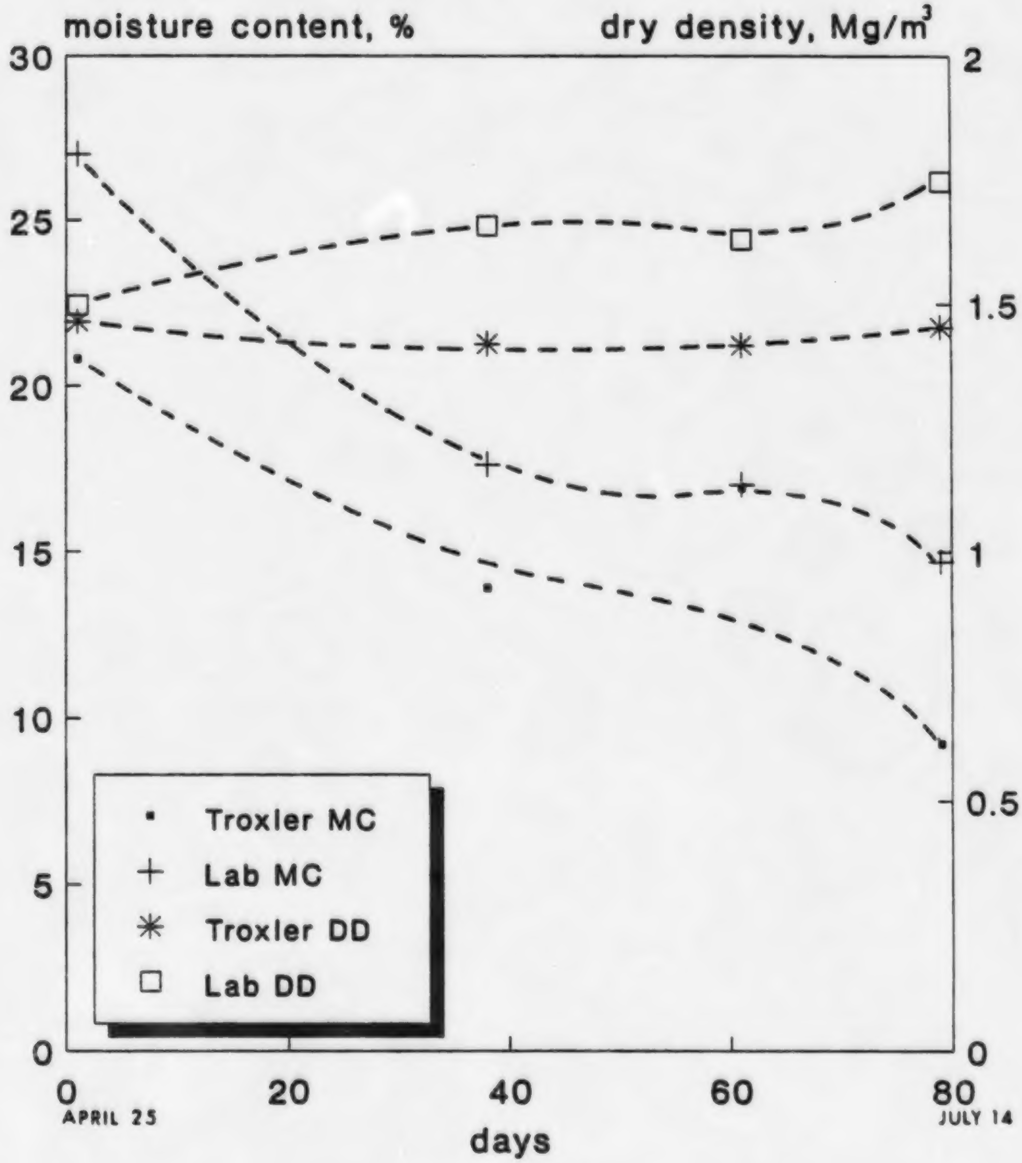


Figure 7.10
1990: Farm Means of Dry Density and Moisture Content; Troxler and Laboratory



It appears that Troxler densities in the summer are influenced by the incidence of soil cracks and macropores to a much greater extent than laboratory measurements which are performed on aggregate samples.

Stastical correlations of Troxler and laboratory measurements were not made as these would have to be specific to each site and seasonal period. Sufficient laboratory tests were carried out and compared with Troxler readings to ascertain that the latter measurements could be used for making valid comparisons of densities and moisture contents.

7.2.8 Soil Crack Measurements and Shrinkage

Figure 7.11 shows a relationship between dry density and crack volume from data collected in 1990 on Farm #1. This plot shows a trend towards increasing soil density as crack volume increases. It should be noted that the density in each case is laboratory determined from aggregates.

Figure 7.12 shows a similar plot of crack volume against laboratory determined moisture content. As expected, this relationship shows increasing crack volume with decreasing moisture content.

Figure 7.13 shows the change in dry density due to shrinkage as affected by initial soil moisture content.

In general these relationships show the following trends:

1. Shrinkage of the soil due to moisture loss leads to increasing soil cracking;

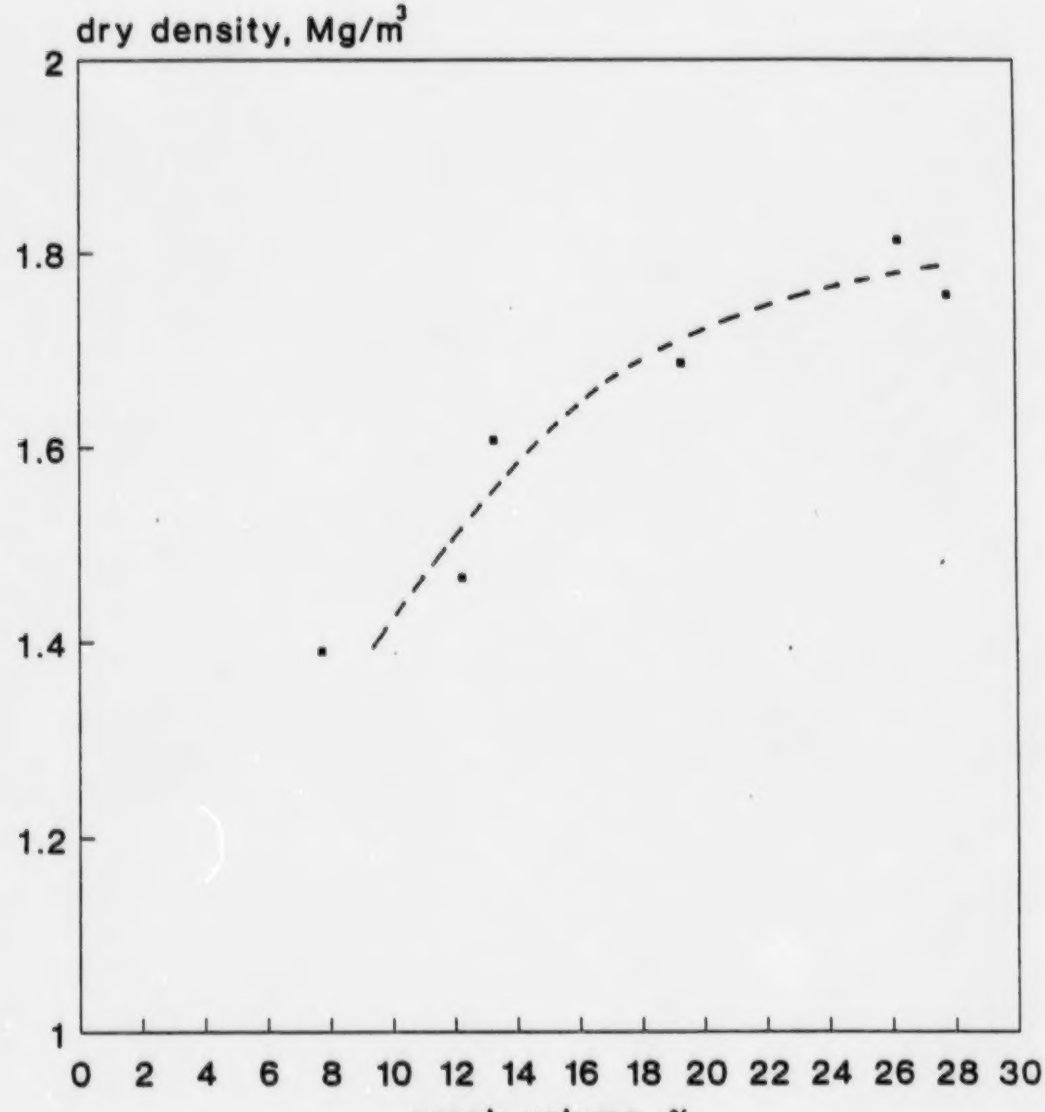
2. Dry density changes appear to be marked at moisture contents ranging between 28% and 16% and reduce thereafter. It would be assumed that the majority of crack development would take place within this moisture content range.

7.3 Drainage Effectiveness

The depth and spacing of tile laterals at the three farm sites were examined for compliance with the recommendations in the Ontario Drainage Guide (Irwin, 1986). Brookston clay is described in the Drainage Guide as having a finer textured B horizon varying from 600-900mm in depth which inhibits drainage. Drains should be installed in the B horizon for best results.

Recommended drain spacing in the Guide for this soil type and profile, for cash crops, is 6m to 15m, and for small grains and forage crops, 12m to 20m. The recommended tile drain depth is 600mm to 700mm. Surface drains are recommended as being necessary. The recommended Drainage Coefficients are 9mm/24hr for improved forage and general grain crops and 12mm/24hrs for cash crops. Minimum recommended grades for laterals in the OMAF Guide vary between 0.05% for smooth 100mm diameter pipe and 0.08% for corrugated 100mm diameter pipe. These gradients apply to drains not subject to sediment accumulation.

Figure 7.11
Aggregate Dry Density(Laboratory) vs Crack Volume(Field) - 1990



Crack Volume =
Volume of Cracks/Total Volume

Figure 7.12
April to July 1990: Crack Volume vs
Laboratory Moisture Content

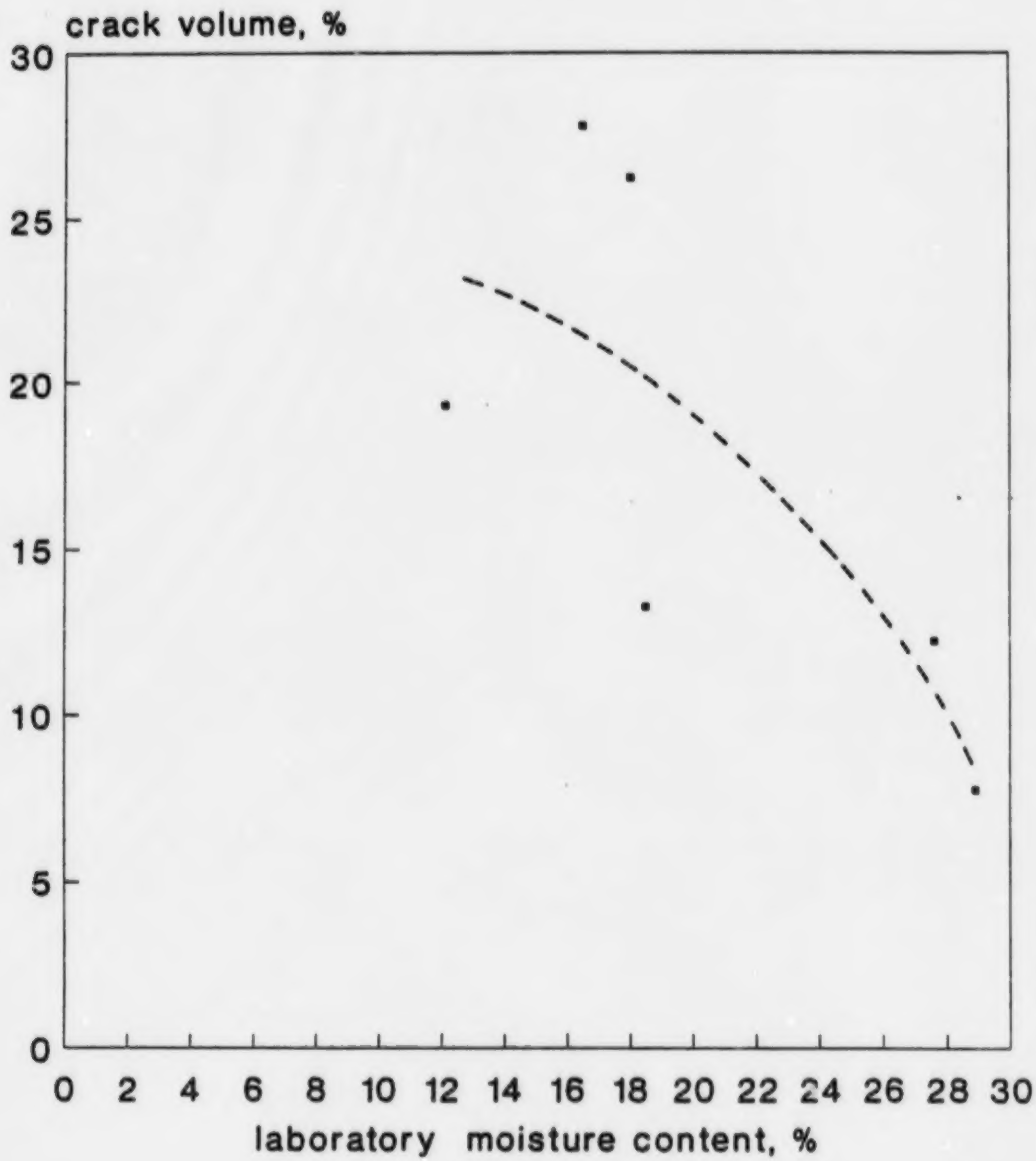
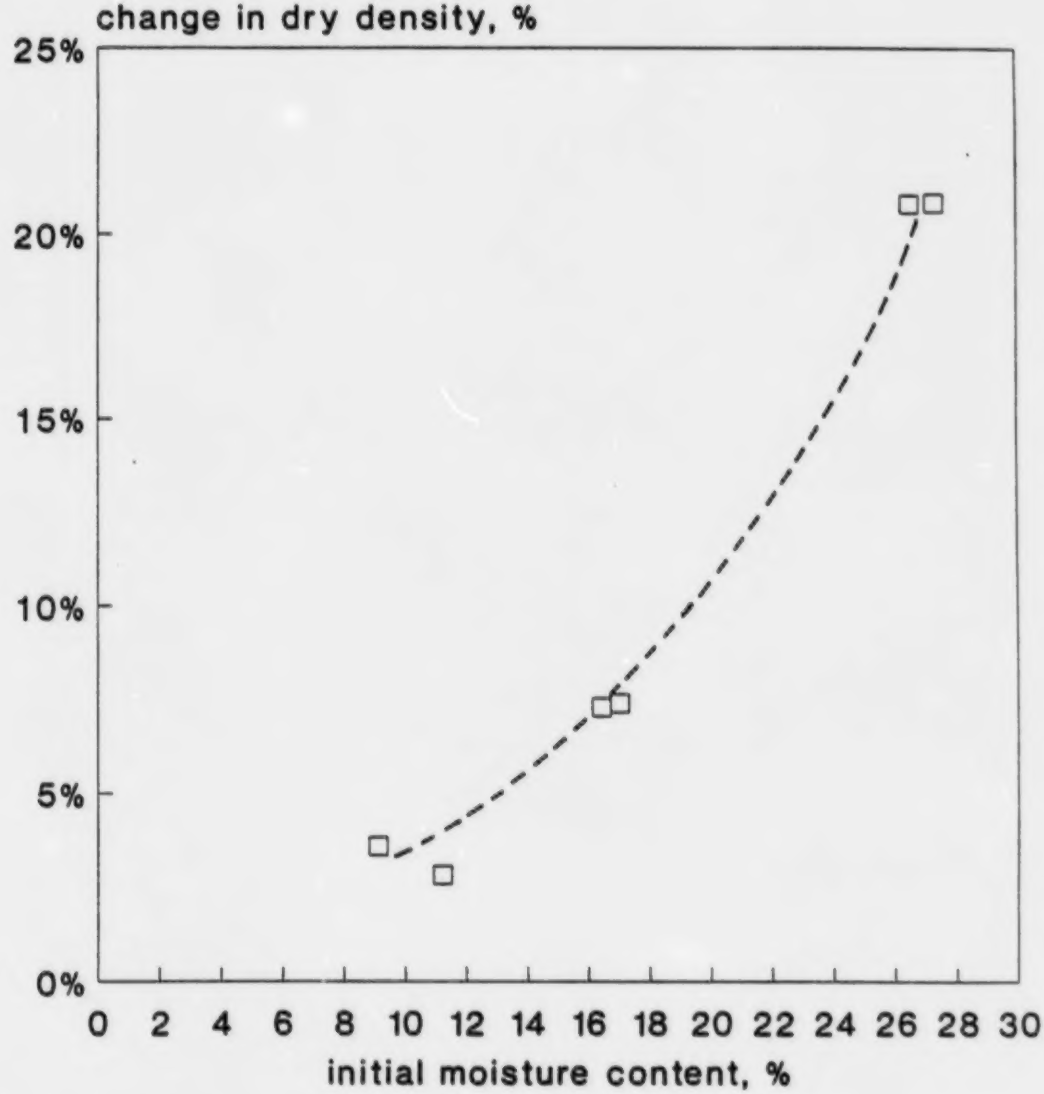


Figure 7.13

Change in Dry Density due to Shrinkage vs Initial Moisture Content: Lab 1990



Change in dry density =
(final-initial)DD/initial DD
Final moisture content = 0%

The three farms had average depths, spacings and gradients of tile drains as shown in Table 7.4 for the areas studied.

Farm #3, with the widest lateral spacing, is marginally outside the Drainage Guide recommendations.

The measured gradients were quite variable, even on the same farm. On Farm #1, a negative gradient was detected on the more recently laid plastic pipe. This may well be inaccurate since plastic tubing will deform by approximately 10% and the distance from the soil surface to the top of the pipe was used in the gradient computation.

Table 7.4 Depths, Spacings and Gradients of Laterals

Farm No	Average Depth (mm)	Average Spacing (m)	Average Gradient (%)* Lateral 1	2**	3**
1	625	6.5	0.47	negative	negative
2	667	10.5	0.15	0.82	0.00
3	750	21.1	0.79	0.14	0.53

* Plastic drains, Laterals 2 and 3, Farm #1 only.

** Measured between Survey Line outlet only.

On Farm #2, there was no gradient detected on one of the laterals. In all other cases, gradients equalled or exceeded the minimum recommended in the OMAF Guide.

7.4 Significance of Results

Mean moisture contents have been used in some relationships. It is considered that the relatively small difference between farms of the means of field measured moisture contents, is not significant because of precipitation differences, the inherent error in such determinations, and the variability and range of measured moisture contents (from 11.5% to 27.1%).

Analysis of variance was applied to the means of moisture contents for the measurements made in July, August and September, 1989, on the three farms. No significant differences were found between the means, reinforcing the above conclusion.

The same technique was applied to mean dry density measurements (Troxler) made in July, August, and September, 1989, on each farm. The farm means were 1.41, 1.45 and 1.48Mg/m^3 for Farms #1, #2 and #3 respectively. A significant difference was found between the means of Farms #2 and #1 and between Farms #3 and #1, but not between Farms #2 and #3. The density data used in this analysis were themselves averages of readings taken on monthly field visits along the survey lines, and with a variability range of 1.2 - 1.6Mg/m^3.

8.0 OBSERVATIONS

It is difficult to draw conclusions within the limitations of a survey type study conducted under uncontrolled conditions, and with comparisons made only between three farms. This is particularly so where these farms had different cropping practices, management, tillage, planting dates and varieties.

Certain trends have been observed in this study, and these will have to be validated by further experimentation or data collection. The information listed below is not necessarily in order of importance.

1 Considerable yield differences were noted between the study farms. It is not possible to clearly link these yield differences with tile spacing and/or crop rotation because of farm conditions, soy bean variety, planting date and other management factors. In addition these yield differences were observed in an atypical growing season when record rainfall occurred in the study area in July 1989.

2. There was no significant increase in density in the top 200mm of soil on Farm #1 which had tomatoes in its rotation. In fact, mean dry densities on this farm were lower than on the other farms. Stone (1987), working on Brookston clay loam with corn and soybean crops observed no increasing trend in bulk density to a depth of 250mm, over a three year period after this soil was subjected to fall and spring compaction. He suggested that the absence of a cumulative increase in bulk density over the duration of his study indicated that if the soil structure is indeed detrimentally affected by surface compaction, this is occurring only slowly. The observed densities on Farm #1 would tend to bear out the above conclusion.

3. A soil moisture content of 19.5%± presents optimum conditions for soil compaction on all three farms, as measured by Standard Proctor tests. "Modified" (lower energy) Proctor Tests indicate that significant compaction can occur at moisture contents up to 23%. Soil moisture contents at harvest below these values therefore results in a reduction of compaction by harvesters and trailed equipment. Stone (1987) working on Brookston clay loam has suggested moisture contents suitable for tillage falling in the range between 20.9% and 27.6%. When moisture is at the upper end of this range, agricultural traffic

should be less harmful to soil structure. It is recognised that at moisture contents beyond the tillage range and up to the Liquid Limit (i.e. 28% up to 40%±), traction problems, wheel slip and smearing will rise in proportion to any soil moisture increase.

4. The highest average soil density was measured on the farm with the widest tile drain lateral spacing. The lowest density was observed on the farm with the narrowest tile drain lateral spacing. Intermediate soil density was observed on the farm with intermediate tile drain spacing. All densities were below those obtained in Standard (25 blows) and "Modified" (10 blows) Proctor tests and were not excessive. Higher densities were observed at the 200mm depth than at the 100mm depth at all farm sites.

5. For the sites studied, no marked difference was observed when comparisons were made of surface soil density immediately over the tile and in the region between the laterals. There would therefore be no particular benefit in limiting agricultural traffic to specific regions in the field based on tile location and any associated density differences.

6. The groundwater was below tile drain invert level during most of the summer and early fall of 1989, despite it being a wet growing season. This trend was also noted in the summer of 1990.

7. Rains of 25mm± in the summer are frequently insufficient to raise water levels above tile drain level. Subsurface drains are therefore considered to be largely non functional during the summer months.

8. Observations indicate extensive cracking of the soil during dry months. These cracks would serve to conduct rain water downward into the soil profile and to drain tile invert levels relatively quickly.

   Limited measurements show cracks can take up to 25% of the volume of the upper 200mm of surface soil during mid summer.

9. Differences in hydraulic conductivity have been noted under spring (saturated) and summer (unsaturated) conditions. Piezometer calculations indicate a hydraulic conductivity of 4.7 - 9.2 x 10^{-9}m/sec in the spring. Guelph Permeameter measurements indicate hydraulic conductivities in the range of 1.8 - 2.8 x 10^{-4}m/sec in the summer. In addition to the difference in degree of saturation, extensive cracking in the upper levels of the soil profile probably contributes to the significantly higher hydraulic conductivities observed under dry conditions.

10. Farms #1 and #2 both have tile drain spacings which fall within the Drainage System criteria for Brookston clay as set out in the Drainage Guide for Ontario. Farm #3 is drained marginally outside these guidelines. Some of the tile drains on Farms #1 and #2 appear to be installed with doubtful gradients. In so stating, it is recognised that gradient measurements were made on these sites

over relatively short distances. Over longer distances, the average gradients may be quite satisfactory. In addition, deformation of plastic drain tubing would affect the gradient computations on Farm #1.

11. Laboratory studies show a definite relationship between shrinkage and moisture content. Analysis of this relationship indicates that at higher moisture contents, a greater degree of shrinkage can be expected. The studies would seem to indicate that for wetter initial soil conditions, a greater degree of soil cracking could be expected upon drying than for a soil with low initial moisture content. This hypothesis should be field tested.

9.0 RECOMMENDATIONS

The recommendations given below are based on the results obtained from this study and the tentative conclusions reached.

1. Trends have been observed towards lower soil densities and higher yields on farms with more closely spaced laterals. Based on the limited nature of the study, these trends appear to be independent of intensive cropping in the rotation. These trends need to be confirmed or negated by controlled plot type or farm scale experiments before such a conclusion can be defended.

2. Controlled experiments are required to test the efficacy of tile drain blockage.

   Indications are that soil cracking alters the hydraulic characteristics of the soil. Such cracks tend to promote quick downward movement of rain water to tile drain level. Water table levels also appear to be consistently below tile drain invert level during the summer.

   Rainfall therefore appears to be removed from a field before it can uniformly wet the soil profile, due to rapid transport of water through soil cracks and macropores into subsurface drainage or to levels below the drain system. This observation tends to be borne out by continued high soil tension readings during the summer even after significant measurable rainfall.

   Dissolved agricultural chemicals may quickly find their way into collection ditches and natural watercourses after large summer rainfall events. At such times there may be a case for controlling the outflow from tile drains. Such a practice would help improve soil moisture retention and reduce nutrient or pesticide discharge.

   Field relationships between crack volume, soil moisture and hydraulic conductivity (van der Tak and Grismer, 1987) should be studied in greater detail. Such a study would improve the irrigation-drainage management of Brookston clay soils.

For example, soil profile wetting and leaching might be improved by frequent irrigation when cracks are deep enough to enhance water application uniformity and soil aeration but not so deep as to limit the wetting and leaching of the root zone.

3. Limited information has been obtained on natural water levels under late spring conditions. Further information on water characteristics, including hydraulic conductivity, should be obtained for this soil at a number of locations.

4. Mole drainage may be an alternative treatment which could be considered for these soils of high clay content and plasticity. Mole drain trials are therefore recommended for these soils.

5. A study of the County with Brookston clay soil should be conducted at the macro level to obtain data on existing tile drain spacing and crop yields. This should be basically an information gathering exercise. Statistical treatment of the data, from about 50 to 60 farm sites, should suppress varietal and other differences and may yield an indication of the effectiveness of different tile drain spacings.

6. Measurements of the optimum moisture content for compaction on Brookston clay loam (based on Proctor density tests) indicate that traffic on this soil should be avoided at moisture contents between 19% and 23%. From field observations made in this study, the majority of harvesting traffic occurs at moisture contents below those quoted above. Compaction effects of harvesting equipment for intensive crops, eg. tomatoes, should therefore be minimal, except in "wet" harvesting years. Measured soil densities at depths down to 200mm on the experimental sites do not appear to be excessive. Densities at depths greater than 200mm were not measured. It is possible that these subsoil densities could have an effect on crop yields, for crops with roots penetrating such depths. This therefore represents an area for further study.

10.0 CLOSURE

Strata Engineering Corporation gratefully acknowledges the cooperation and assistance of Dr. W. Findlay of Agricultural Canada, Harrow Research Station. Important inputs and advice were also provided by Messrs. David Charlton and George Schell of Ecological Services for Planning Ltd., Guelph.

Farmer cooperators, Messrs. Robert Chauvin and Hermas Moison of Essex County are thanked for providing the experimental sites and for collecting rainfall data.

The assistance of OMAF personnel, and in particular Mr. Ed Tomacek, in supplying farmer's names for site selection, is gratefully recognized.

Respectfully Submitted:
STRATA ENGINEERING CORPORATION

M. J. Percy, P.Eng. Project Leader	C. Mirza, P.Eng. Project Manager

11.0 REFERENCES CITED

American Society of Agricultural Engineers. 1962. Measuring saturated hydraulic conductivity of soils. ASAE, St. Joseph, Mich.

Amir, I., Raghavan, G. S. V., McKyes, E. and Broughton, R.S. 1976. Soil compaction as a function of contact pressure and soil moisture content. Can. Agr. Eng. 18 (1): 54-57.

Arndt, W. and Rose, C.W. 1966. Traffic compaction of soil and tillage requirements. J. Agr. Eng. Res. 11(3): 170-187.

Barnes, K. K., Carleton, W. M., Taylor, H. M., Throckmorton, R. I. and Vandenberg, G. E. 1971. Compaction of agricultural soils. Trans. Amer. Soc. Agr. Eng. pp:30-37, 190-198.

Bilanski, W. K. and Varma R. K. 1976. Effect of bulk density and moisture tension on corn shoot growth. Trans. Amer. Soc. Agr. Eng. 19 (2): 337-340.

Bolton, E. F. and Aylesworth, J. W. 1959. Effect of tillage traffic on certain physical properties and crop yields on a Brookston clay soil. Can. J. Soil Sci. 39 (2): 98-102.

Bouma, J., Hillel, D. I., Hole F. D., and Amerman, C. R. 1971. Field measurement of unsaturated hydraulic conductivity by infiltration through artificial crusts. Soil Sci. Amer. Proc. 35 (2): 362-364.

Bouwer, H. and Van Schilfgaarde, J. 1963. Simplified method of predicting fall of water table in drained land. Trans. Amer. Soc. Agr. Eng. 6 (4): 288-291, 296.

Bouwer, H. and Jackson, R. D. 1974. Determining soil properties. Drainage for Agriculture ASA Monograph 17. J. Van Schilfgaarde (Ed), Amer. Soc. Agronomy.

Buckland, G. D., Sommerfeldt, T. G. and Harker, D. B. 1987. A field Comparison of Transient Drain Spacing Equations in a Southern Alberta Lacustrine Soil. Trans. Amer. Soc. Agr. Eng. 30(1): 137-142.

Daniel, D. E. 1989. In situ hydraulic conductivity tests for compacted clay. J. Geotechnical Eng. Div. Amer. Soc. Civil Eng. 115 (9): 1205-1226.

Djokoto, I.K., Bigsby, F. W., and Lal, R. 1971. Soil compaction by agricultural land packers and models. Can. Agr. Eng. 13 (2):46-50.

Dorsey, J. D., Ward, A. and Fausey, N. 1989. A comparison of field hydraulic conductivity measurement techniques on two Ohio soils. Paper No. 892190. ASAE/CSAE International Meeting, Québec, Canada.

Douglas, E., McKyes, E., Taylor, F., Negi, S. and Raghavan, G. S. V. 1980. Unsaturated hydraulic conductivity of a tilled clay soil. Can. Agr. Eng. 22 (2): 153-161.

Dumm, L. D. 1964. Transient flow concept in subsurface drainage: Its validity and use. Trans. Amer. Soc. Agr. Eng. 7 (2): 142-146, 151.

Ernst, L. F. 1956. Calculation of the steady flow of groundwater in vertical cross sections. Netherlands J. Agr. Sci. 4: 126-131.

Feldman, M. and Domier, K. W. 1970. Wheel traffic effects on soil compaction and growth of wheat. Can. Agr. Eng. 12 (1): 8-11.

Freitag, D. R. 1968. Penetration tests for soil measurements. Trans. Amer. Soc. Agr. Eng. 11 (6): 750-753.

Gameda, S., Raghavan, G. S. V., McKyes, E. and Theriault, R. 1985. A review of subsoil compaction and crop response. Proc. Int. Conf. on Soil Dynamics. Auburn, Alabama, 5: 970-978.

___________. **1987**. Subsoil compaction in a clay soil: I. Cumulative effects. Soils & Tillage Research. 10: 113-122.

___________. **1987**. Single and dual probes for soil density measurement. Trans. Amer. Soc. Agr. Eng. 30 (4): 932-934, 944.

Gill, R. and Reaves, C. A. 1956. Compaction patterns of smooth rubber tires. Agr. Eng. 37: 637-680, 684.

Guyon, G. 1967. Considerations sur l'hydraulique du drainage des nappes. Bull. Tech du Genie Rural No. 70, Antony, France.

Hammad, H. Y. 1962. Depth and spacing of tile drain systems. J. Irrigation and Drainage Div., Amer. Soc. Civil Eng. 88: 15-34.

Hardy, F. and Derraugh, L. F. 1947. The water and air relations of some Trinidad sugar-cane soils. Tropical Agriculture, 24: 76-87.

Hillel, D., Krentos V. D., and Styllianou, Y. 1972. Procedure and test of an internal drainage method for measuring soil hydraulic characteristics in situ. Soil Sci. 114 (5): 395-400.

Hogentogler, C. A. 1936. Essentials of soil compaction. Proc. Highway Res. Board, National Res. Council, Washington, D.C., pp: 309-316.

Hooghoudt, S. B. 1940. Bijdragen tot de kennis van enige natuurkundige grootheden van de grond, No. 7. Versl. Landbouwk, Onderz, 46: 515-707.

Hoogmoed, W. B. and Bouma, J. 1980. A simulation model for predicting infiltration into cracked clay soil. J. Soil Sci. Soc. Amer. 44: 458-461.

Hoover, J. R. and Jarrett, A. R. 1989. Field evaluation of shallow subsurface drains to vent soil air, improve infiltration, and reduce runoff. Trans. Amer. Soc. Agr. Eng. 32 (4): 1358-1364.

Hudson, A. W., Hopenwell, H. G., Bowler, D. G. and Cross, M. W. 1962. The Draining of Farm Lands. Massey Agricultural College, University of New Zealand. Palmerston. 2nd. Rev. Ed., 319 pp.

Hvorslev, M. J. 1949. Subsurface Exploration and Sampling of Soil for Civil Engineering Purposes. The Engineering Foundation, New York, N.Y. 521 p.

Irwin, R. W. 1986. Drainage Guide for Ontario. Ontario Ministry of Agriculture and Food, Publication 29. Published by Information Branch OMAF, Legislative Building, Toronto.

Irwin, R. W., Bryant, G. J., Toombs, M. R. and Stone, J. A. 1987. Evaluation of a drainage coefficient for Brookston clay soil. Trans. Amer. Soc. Agr. Eng. 30 (5): 1343-1346.

Jamison, V. C., Weaver, H. A. and Reed, I. F. 1950. Distribution of tractor tire compaction effects in Cecil clay. Proc. Soil Sci. Soc. Amer. 15: 34-37.

Kanwar, R. S. 1989. Effect of tillage systems on the variability of soil water tensions and soil water content. Trans. Amer. Soc. Agr. Eng. 32 (2): 605-610.

Kanwar, R. S., Rizvi, H. A., Ahmed, M. and Horton, R. 1989. Measurement of field saturated hydraulic conductivity by using Guelph and Velocity permeameters. Trans. Amer. Soc. Agr. Eng. 32 (6): 1885-1890.

Kirkham, D. 1958. Seepage of steady rainfall through soil into drains. Trans. Amer. Geophysical Union, 39: 892-908.

Lambe, T. W. 1960. Structure of compacted clay. Trans. Amer. Soc. Civil Eng. 125: 682-705.

Larney, F. J., Kladivko, E. J. and Monke, E. J. 1988. Subsurface drain spacing effects on soil moisture regime of Clermont silt loam. Trans. Amer. Soc. Agr. Eng. 31 (4): 1128-1134.

Lemon, E. R. and Erickson, A. E. 1952. The measurement of oxygen diffusion in the soil with a platinum microelectrode. Proc. Soil Sci. Soc. Amer. 16: 160-164.

Lyles, L. and Woodruff, N. P. 1963. Effects of moisture and soil packers on consolidation and cloddiness of soil. Trans. Amer. Soc. Agr. Eng. 6: 273-275.

Maasland, M. and Haskey, H. C. 1958. The auger hole method of measuring the hydraulic conductivity of soil and its application to tile drainage problems. Paper presented at International Commission on Irrigation and Drainage. Third Congress, San Francisco, California.

McKyes, E., Negi, S., Douglas, E., Taylor, F. and Raghavan, G. S. V. 1979. The effect of machinery traffic and tillage operations on the physical properties of a clay and on yield of silage corn. J. Agr. Eng. Res. 24: 143-148.

Negi, S., McKyes, E., Taylor, F., Douglas, E. and Raghavan, G. S. V. 1980. Crop performance as affected by traffic and tillage in clay soil. Amer. Soc. Agr. Eng. Trans. 23 (6): 1364-1368.

Olson, R. W. 1963. Effective stress theory of soil compaction. J. Soil Mechanics and Foundations Div. Amer. Soc. Civil Eng. 89 (SM 2): 27-45.

Ontario Ministry of Agriculture and Food. 1939 (Reprinted March 1989). Richards N. R., Caldwell, A. G. and Morwick, F. F., Soil Survey of Essex County. Report No. 11 of the Ontario Soil Survey, OMAF.

Proctor, R. R. 1933. Fundamental principles of soil compaction. Engineering News-Record, McGraw-Hill Publ. Co. Inc. New York, N.Y., vol. 111, p. 286.

Raghavan, G. S. V., McKyes, E., Gendron, G., Borglum, B. K., and Le, H. H. 1978. Effects of tire contact pressure on corn yield. Can. Agr. Eng. 20: 34-37.

Raghavan, G. S. V. and McKyes, E. 1983. Physical and hydraulic characteristics in compacted clay soils. J. Terramechanics, 19 (4): 235-242.

Rao, S. A. A., Hay, R. C. and Bateman, H. P. 1960. Effect of minimum tillage on physical properties of soils and crop response. Trans. Amer. Soc. Agr. Eng. 3 (2): 8-10.

Reynolds, W. D. and Elrick, D. E. 1985. Measurement of field saturated hydraulic conductivity, sorptivity and the conductivity-pressure head relationship using the "Guelph Permeameter". Proc. National Water Well Association Conf. on Characterization and Monitoring of the Vadose (Unsaturated) Zone. Denver, Colorado, 25 pp.

Rycroft, D. W. 1972. A review of literature on mole drainage. Technical Bulletin 72/10. Field Drainage Experimental Unit, Cambridge, U.K.

Shady, A. M., Broughton, R. W., Bernier, Y., Delisle, U. and Sylvestre, G. 1976. Experience with production scale field measurements of hydraulic conductivity. Third National Drainage Symposium Proceedings, Amer. Soc. Agr. Eng.

Soane, B. D. 1970. The effect of traffic and implements on soil compaction. J. Proc. Inst. Agr. Eng. 25: 115-126.

Soehne, W. 1958. Fundamentals of pressure distribution and soil compaction under tractor tires. Agr. Eng. 39: 276-281, 290.

Stone, J. A. 1987. Compaction and the surface structure of a poorly drained soil. Trans. Amer. Soc. Agr. Eng. 30: 374-378.

Sylvestre, G., Boudreau, A. and Bernier, Y. 1989. Subsurface drainage design field

performance. Paper No. 89-2065, ASAE/CSAE Meeting, Québec, Canada.

Tabrizi, A. N. and Skaggs, R. W. 1982. Variation of saturated hydraulic conductivity within a soil series. Amer. Soc. Agr. Eng. Paper No. 83-2044.

Taylor, F., Raghavan, G. S. V., McKyes, E., Negi, S. and Stemshorn, E. 1981. Soil structure and corn yields. Trans. Amer. Soc. Agr. Eng. 24 (6): 1408-1411.

Theobald. G. H. 1963. Methods and machines for tile and other tube drainage. FAO, U.N. Agr. Dev. Paper No. 78, 104 pp.

Trafford, B. D. and Massey, W. 1975. A design philosophy for heavy soils. Tech. Bull. 75/5, Field Drainage Experimental Unit, Cambridge, U.K.

van der Tak, L. D. and Grismer, M. E. 1987. Irrigation, drainage and soil salinity in cracking soils. Trans. Amer. Soc. Agr. Eng. 30 (3): 740-744.

Van Doren, D. M., Jr., Brown, W. N. and Johnson, W. H. 1964. Soil compaction and crop growth. Ohio Agr. Eng. Sta. June.

Van Schilfgaarde, J. 1963. Design of tile drainage for falling water tables. J. Irrigation and Drainage Div. Amer. Soc. Civil Eng. 89: 1-11.

______________. **1964.** Closure, Design of tile drainage for falling water tables. J. Irrigation and Drainage Div. Amer. Soc. Civil Eng. 90: 71-73.

Waelti, H., Liljedahl, J. B., and Monke, E. J. 1963. Field instrument measures soil compaction. Agr. Eng. August, pp: 438-439.

Weaver, H. A. and Jamison, V. C. 1951. Effects of moisture on tractor tire compaction of soil. Soil Sci. 71: 15-23.

Weil, C., Natho-Jina, S. and Chambers, R. 1989. The feasibility of mole drainage in silicate clay soils subjected to freezing. Paper No. 89-2063, ASAE/CSAE Meeting, Québec, Canada.

Yaalon, D. H. and Kalmar, D. 1984. Extent and dynamics of cracking in a heavy clay soil with xeric moisture regime. Proc. ISSS Symposium on Water and Solute Movement in Heavy Clay Soils, ILRI #3, The Netherlands.

APPENDIX

FIGURES

TABLES

APPENDIX - continued

DRAWINGS

SKETCHES

MISCELLANEOUS

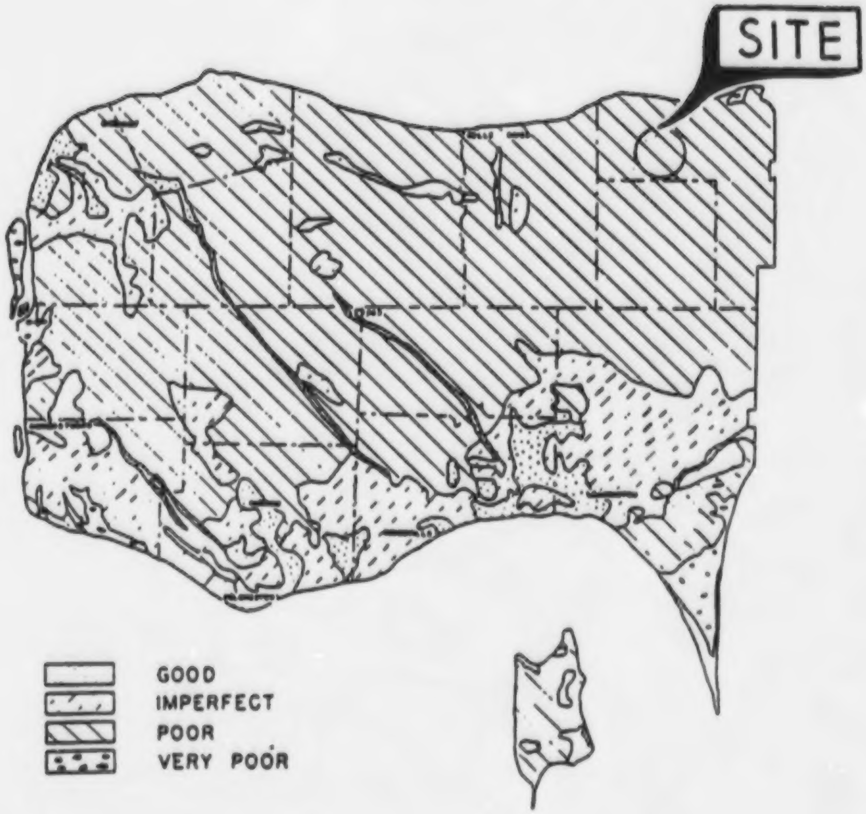
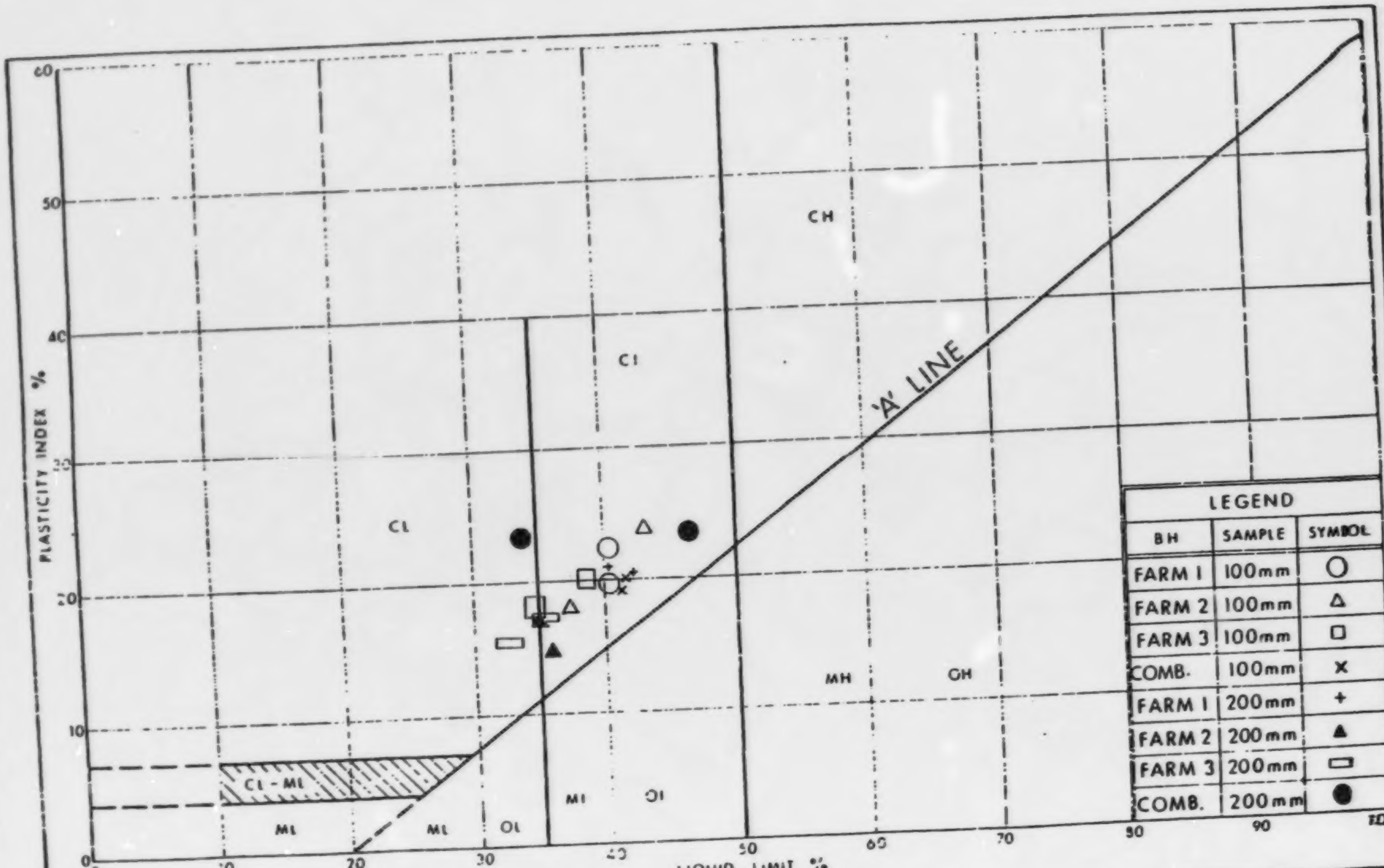


Fig A4.1 Essex County Outline Map showing soils with good, imperfect poor and very poor natural drainage.

(Soil Survey of Essex County - Report No. 11 of the Ontario Soil Survey reprinted Mar. 1989)

Fig A4.2 Drainage System of Essex County

(Soil Survey of Essex County Report No. 11 of the Ontario Soil Survey reprinted Mar. 1989)



STRATA ENGINEERING CORP.	PLASTICITY CHART AGRICULTURE CANADA	FIG NO	A 6.1
		PROJECT	S-89-257
		SITE	ESSEX COUNTY

Table A5.1: Depth, Spacing, Diameter and Material Composition of Drain Laterals

	Depth to Tile (m)		Lateral Spacing (m)		Nominal Tile Diameter	Tile Material
Tile Line	*SL1	*SL2	*SL1	*SL2	mm	
Farm1						
1	0.56	0.55			100	clay
			6.66	6.58		
2	0.65	0.65			100	plastic
			6.25	6.40		
3	0.67	0.67			100	plastic
Farm2						
1	0.70	0.56			100	clay
			10.26	10.21		
2	0.78	0.69			100	clay
			10.69	10.95		
3	0.70	0.59			100	clay
Farm3						
1	0.66	0.72			100	clay
			20.30	20.94		
2	0.74	0.78			100	clay
			21.34	21.82		
3	0.81	0.79			100	clay

* SL1 - Survey Line 1
SL2 - Survey line 2

Table A5.2 Tile Depth and Gradient

Farm & Survey Line	Elev. Grd. (m)	Tile Depth (m)	Tile Elev. (m)	Outlet Elev. (m)	Elev. Diff. (m)	Gradient (%)
Farm #1 Survey Line 1						
Tile Line 1	98.04	0.56	97.48	97.41	0.07	0.5
Tile Line 2	98.06	0.65	97.41	97.47	0.06	neg
Tile Line 3	98.11	0.76	97.41	97.54	0.10	neg
Farm #1 Survey Line 2						
Tile Line 1	98.08	0.55	97.53	97.41	0.12	0.3
Tile Line 2	98.08	0.65	97.43	97.47	0.04	neg
Tile Line 3	98.08	0.67	97.41	97.54	0.13	neg
Farm #2 Survey Line 1						
Tile Line 1	99.02	0.70	98.32	98.30	0.02	0.1
Tile Line 2	99.01	0.78	98.23	98.05	0.18	0.6
Tile Line 3	99.03	0.70	98.33	98.35	0.02	neg
Farm #2 Survey Line 2						
Tile Line 1	98.93	0.56	98.37	98.30	0.07	0.2
Tile Line 2	98.94	0.69	98.25	98.05	0.20	0.4
Tile Line 3	98.92	0.57	98.35	98.35	0.00	0.0
Farm #3 Survey Line 1						
Tile Line 1	100.0	0.66	99.34	99.02	0.32	1.0
Tile Line 2	99.94	0.74	99.20	99.16	0.04	0.1
Tile Line 3	99.97	0.81	99.16	98.97	0.19	0.6
Farm #3 Survey Line 2						
Tile Line 1	100.06	0.72	99.34	99.02	0.32	0.5
Tile Line 2	100.03	0.78	99.25	99.16	0.09	0.1
Tile Line 3	100.02	0.79	99.23	98.97	0.26	0.4

Notes

Farm 1- Distance Survey Line 2 to Survey Line 1 - 30m
Distance Survey Line 1 to ditch bank tile outlet - 15m

Farm 2- Distance Survey Line 2 to Survey Line 1 - 30m
Distance Survey Line 1 to ditch bank tile outlet - 15m

Farm 3 - Distance Survey Line 2 to Survey Line 1 - 30m
Distance Survey Line 1 to ditch bank tile outlet - 32m

Elevations are not geodetic. Arbitrary bench marks selected.

Table A6.1
Moisture Content (Troxler) Measurements - 1989

Farm 1

Location	Moisture Content % 4" July 13	4" Aug. 31	4" Sept 24	8" July 13	8" Aug. 31	8" Sept 24
1/1	13.75	26.40	19.60	12.40	25.20	16.90
1/1M	14.90	25.70	19.00	13.90	25.10	18.60
1/2	16.60	24.60	21.70	15.30	21.20	19.90
1/2M	12.80	24.90	21.50	12.60	23.70	18.30
1/3	13.60	21.90	21.40	13.20	23.70	22.20
2/1	15.30	24.50	18.40	14.00	23.50	16.20
2/1M	15.20	21.00	19.80	13.80	21.10	17.40
2/2	13.80	24.60	18.90	13.10	20.90	15.00
2/2M	12.20	22.00	19.00	11.50	19.00	16.30
2/3	13.40	21.80	14.60	13.10	19.10	16.80

Farm 2

Location	Moisture Content % 4" July 13	4" Aug. 31	4" Sept 25	8" July 13	8" Aug. 31	8" Sept 25
1/1	18.30	24.50	21.40	18.00	24.60	20.30
1/1M	17.50	27.10	22.90	16.40	26.50	22.20
1/2	16.40	24.60	18.40	15.90	23.30	17.90
1/2M	15.40	22.90	21.10	15.30	24.80	21.20
1/3	15.10	21.40	18.10	16.80	20.40	18.30
2/1	15.10	18.00	19.50	14.30	18.10	17.30
2/1M	15.70	25.20	24.60	14.00	21.10	25.00
2/2	17.50	21.20	22.30	16.90	18.50	22.40
2/2M	16.60	19.90	16.80	15.00	18.10	14.00
2/3	16.00	19.10	15.70	15.30	18.00	15.80

Farm 3

Location	Moisture Content % 4" July 26	4" Aug. 30	4" Sept 24	8" July 26	8" Aug. 30	8" Sept 24
1	19.70	23.40	17.00	17.50	20.30	15.90
2	25.00	22.80	17.40	22.70	19.80	16.90
3	23.40	19.80	20.20	22.10	19.70	18.80
4	22.30	20.70	19.40	20.20	22.70	17.70
5	23.20	22.30	19.20	19.60	21.20	16.60
6	20.70	22.40	16.70	20.70	20.30	15.20
7	21.30	21.20	16.80	21.10	21.50	13.70
8	23.70	18.00	15.50	22.10	19.20	15.10
9	20.50	20.50	16.30	21.90	17.40	16.60
10	20.10	19.20	16.90	20.90	18.40	14.10
11	21.50	20.60	17.70	20.20	18.20	13.10
12	20.20	18.40	16.40	19.20	16.40	15.80
13		22.20	20.50		23.30	18.40
14		25.30	20.10		22.80	18.40
15		23.80	18.40		22.30	17.00
16		24.60	17.30		22.30	15.40
17		19.30	15.50		18.30	14.90
18		25.20	19.60		24.50	16.80
19		21.00	17.50		18.40	17.00
20		24.30	21.00		22.60	18.00
21		22.90	18.30		22.00	16.30
22		25.50	21.60		21.30	16.40
23		23.00	20.80		21.50	19.60
24		22.70	13.00		20.80	17.60

Table A6.2 DRY DENSITY AND MOISTURE CONTENT (Troxler& Laboratory)
Farm 1 / 1990

Location	Depth	MC,% Lab	MC,% Trox	DD,Lab kg/m3	DD,Trox kg/m3
			April 26		
1	4"	24.9	21.8	1558	1457
1	8"	25.5	20.6	1557	1535
1M	4"	25.3	18.0	1503	1461
1M	8"	24.8	16.5	1577	1553
2	4"	27.0	21.5	1508	1420
2	8"	26.1	19.4	1530	1538
2M	4"	29.0	20.4	1531	1442
2M	8"	27.6	18.2		1542
3	4"	28.3	20.4	1460	1460
3	8"	26.8	20.1	1396	1524
control1	4"	26.9	25.6	1549	1360
control1	8"	20.3	21.3	1566	1492
control2	4"				
control2	8"				
random1	4"	29.0	22.2	1450	1397
random1	8"	27.8	21.1	1434	1477
random2	4"	26.0	24.0	1443	1319
random2	8"	22.3	21.9	1523	1437
			June 02		
1	4"	17.0	12.6	1614	1394
1	8"		12.9		1452
1M	4"	17.1	16.2		1291
1M	8"		14.0		1410
2	4"	17.0	12.7	1705	1503
2	8"		11.9		1601
2M	4"	18.3	14.8	1644	1295
2M	8"		14.1		1420
3	4"	18.4	15.6		1335
3	8"	17.6	14.6		1482
			June 25		
1	4"	18.4	17.9	1425	1392
1	8"	17.2	15.2		1485
1M	4"	17.2	18.2		1322
1M	8"	15.5	17.0		1400
2	4"	16.9	19.5	1501	1322
2	8"	16.9	17.3		1412
2M	4"	15.7	17.2		1344
2M	8"	17.0	15.9		1434
3	4"	14.0	15.9		1246
3	8"	16.0	14.3		1320
control1	4"	18.3	16.0	1640	1466
control1	8"	17.4	19.1	1770	1571
control2	4"	18.0	15.3	1568	1511
control2	8"	17.0	17.3	1697	1585
			July 13		
1	4"	13.4	8.0		1501
1	8"		9.0		1541
1M	4"		9.1		1336
1M	8"		9.6		1468
2	4"	12.0	8.6		1425
2	8"	15.3	8.2		1423
2M	4"	10.4	9.1		1413
2M	8"	16.7	7.4		1516
3	4"	11.7	7.9		1344
3	8"		6.9		1451
control1	4"	20.1	14.1	1793	1465
control1	8"	19.2	12.9		1553

MC = Moisture Content DD = Dry Density

Table A6.3
Dry Density(Troxler) Measurements - 1989

LOCATION	Dry Density, kg\m3					
	4"depth			8"depth		
Farm1	July 13	Aug 31	Sept 24	July 13	Aug. 31	Sept 24
1/1	1351	1275	1408	1460	1296	1559
1/1M	1518	1420	1473	1609	1417	1551
1/2	1360	1349	1381	1498	1513	1458
1/2M	1553	1367	1392	1587	1442	1498
1/3	1495	1388	1383	1606	1436	1455
2/1	1177	1245	1303	1296	1248	1394
2/1M	1238	1405	1320	1336	1447	1436
2/2	1221	1256	1323	1285	1394	1487
2/2M	1407	1360	1360	1481	1481	1503
2/3	1367	1291	1444	1484	1421	1518
Farm 2						
1/1	1460	1396	1508	1503	1425	1599
1/1M	1425	1328	1442	1505	1391	1502
1/2	1484	1396	1514	1548	1428	1567
1/2M	1455	1450	1510	1498	1445	1538
1/3	1508	1402	1344	1481	1436	1434
2/1	1482	1445	1428	1566	1447	1524
2/1M	1375	1275	1375	1534	1444	1396
2/2	1457	1322	1444	1511	1436	1476
2/2M	1423	1394	1442	1558	1466	1558
2/3	1381	1338	1460	1477	1421	1556
Farm 3						
1	1519	1433	1466	1611	1535	1595
2	1348	1394	1408	1449	1510	1537
3	1413	1516	1365	1498	1551	1450
4	1453	1431	1365	1542	1461	1487
5	1423	1394	1380	1543	1500	1522
6	1413	1386	1447	1506	1526	1590
7	1425	1431	1466	1538	1477	1625
8	1455	1577	1473	1527	1583	1583
9	1558	1410	1452	1535	1537	1569
10	1502	1530	1468	1492	1601	1633
11	1444	1415	1482	1550	1492	2063
12	1522	1567	1477	1543	1676	1591
13		1407	1391		1447	1498
14		1364	1405		1489	1503
15		1383	1431		1476	1535
16		1449	1529		1497	1660
17		1453	1463		1494	1554
18		1319	1397		1449	1538
19		1524	1561		1572	1604
20		1290	1415		1389	1521
21		1328	1463		1426	1543
22		1283	1283		1412	1469
23		1317	1351		1437	1453
24		1338	1397		1452	1489

TABLE A6.4

Piezometer Water Level Measurements July - September 1989

Date	Farm #	Survey Line	Water Level Depths from Ground Level (m) — Tile Line 1	1M	2	2M	3	Remarks
1989 07 07	1	SL 1	*NR	0.79	NR	NR	NR	
		SL 2	NR	NR	NR	NR	0.83	Farm 3 not yet selected
1989 07 07	2	SL 1	0.81	0.85	0.86	0.86	0.79	
		SL 2	0.72	0.81	0.80	0.72	0.69	
1989 07 13	1	SL 1	NR	0.71	NR	NR	NR	
		SL 2	NR	NR	NR	NR	NR	Farm 3 not yet instru-mented
1989 07 13	2	SL 1	0.89	0.88	0.89	NR	NR	
		SL 2	0.71	0.79	0.79	0.71	0.69	
1989 07 27	1	SL 1	**GS	0.07	0.06	0.12	0.15	2.0" to 2.5" rains 89/7/26 and 89/7/27
		SL 2	0.11	0.04	GS	GS	0.04	
1989 07 27	2	SL 1	0.71	0.44	0.79	0.56	0.55	Farm 3 piezo-meters install-ed but no read-ings taken
		SL 2	0.53	0.06	0.69	0.02	0.21	
1989 08 17	1	SL 1	^0.73	NR	NR	NR	NR	^Taped cover o[n] piezo-meters partial-ly open
		SL 2	NR	NR	0.71	NR	^0.78	

*NR - No Reading, piezometer dry
**GS - Water at Ground Surface

TABLE A6.4 (continued...)

Piezometer Water Depths Measurements July - September 1989

Date	Farm #	Survey Line	Water Level Depths from Ground Level (m) Tile Line 1	1M	2	2M	3	Remarks
1989 08 17	2	SL 1	NR	NR	NR	NR	NR	
		SL 2	NR	NR	NR	NR	NR	
1989 08 18	3	SL 1	0.75	0.75	0.76	NR	NR	
		SL 2	NR	0.87	0.84	0.78	0.83	
1989 08 31	1	SL 1	0.78	0.89	0.79	*NR	NR	Farm 1, Farm 2, 1.0" of rain on 89/8/28
		SL 2	NR	NR	0.71	0.71	NR	
1989 08 31	2	SL 1	NR	NR	NR	NR	NR	
		SL 2	NR	NR	NR	NR	NR	
1989 08 30	3	SL 1	0.69	0.72	0.73	0.71	0.71	Farm 3 1.5" of rain on 89/8/28 and 89/8/29
		SL 2	0.75	0.78	0.75	0.70	0.73	
1989 09 24	1	SL 1	NR	NR	NR	NR	NR	
		SL 2	NR	NR	0.72	NR	NR	
	2	SL 1	NR	NR	NR	NR	NR	Farm 2 1.1" of rain on 89/9/22
		SL 2	NR	NR	NR	NR	NR	
1989 09 24	3	SL 1	0.76	NR	NR	NR	NR	
		SL 2	NR	NR	NR	NR	NR	

*NR - No reading, piezomenter dry

Notes: Farm 1 Harvested 1989 10 02
Farm 2 Harvested 1989 10 02
Farm 3 Harvested 1989 09 28

Table A6.5 Farmer Cooperator Rainfall Data (inches)

Date	Location			Remarks
1989	**Stoney Point**	**Tilbury Conc 3**	**St. Joachim**	
July	Farm 1	Farm 2	Farm 3	
19	4.5	3.5	-	Data not recorded on
21	2.5	1.5	-	Farm #3 until 1989 07 26
23	0.5	0.25	2.5	
26	ND*	ND*		
27	-	-	1.0	Estimated by Strata personnel at site
August				
1-6	-	-	0.8	
11	0.5	0.5	-	
21	1.25	1.25	-	
2	-	-	0.6	
28	1.0	1.0	0.9	
29	-	-	0.6	
September				
1	0.5	0.5	-	
7	0.5	0.5	0.4	
8	-	-	0.3	
9	-	-	0.5	
13	0.2	0.1	-	
14	0.3	0.2	0.5	
16	0.4	0.4	-	
22	0.1	1.1	-	
	Harvested 1989 10 02	Harvested 1989 10 02	Harvested 1989 09 28	

* ND = No data recorded

TABLE A 6.6 PIEZOMETER AND TENSIOMETER MEASUREMENTS 1990

Month	Day	Rainfall (mm)	Piezometer Readings (m)				Tensiometer Readings (centibars)			
			P1	P2	P3	P4	T1	T2	T3	T4
May	1									
	2						0	14	56	0
	4	25	D	D	D	D	4	24	6	28
	5						0	2	2	3
	7						0	10	50	20
	9	13	D	D	D	D	0	38	72	42
	11						0	55	80	56
	13									
	14	30	1.03	0.84	0.85	0.95	0	0	0	0
	16	28	0.65	0.40	0.34	0.75	0	2	0	9
	19	8	0.75	0.58	0.50	0.76	4	26	2	20
	22		0.86	0.65	0.55	0.81	8	40	32	31
	24	2	1.01	0.71	0.60	0.91	26	50	46	40
	26		1.08	0.75	0.65	0.95	59	62	64	55
	29		D	0.98	0.78	0.99	82	80	73	62
	31		D	1.02	0.90	1.02	87	87	74	62
June	4	12	D	D	D	D	82	87	74	80
	8	34	D	D	D	D				
	15						65	50	80	86
	18						68	65	80	80
	21						72	80	82	82
	22	9	D	D	D	D	86	86	82	83
	23	6								
	24						88	90	86	86
	27						90	92	88	88
	29		D	D	D	D	90	90	88	88
	30	6	D	D	D	D				
July	4	25	D	D	D	D				
	9	13	D	D	D	D				
	13	30	1.03	0.84	0.85	0.95	-	83	82	82

D = Dry

TABLE A6.7

PLANT AND GRAIN YIELDS FOR FARMS 1, 2, 3

Farm	Variety	Harvest area (m^2)	Plant Mass at Harvest (g)	Grain Mass at Harvest (g)	*Lab. Grain Yield (g)	Lab. Moisture Content (%)	Adjusted Yield 14% Moisture (g)	Unit Yield (Kg/ha)
Farm #1								
SL 1	S 2424	13.1	11350	4540	4150	11.4	5096	3890
SL 2	Pioneer	13.1	9534	3632	3080	10.3	4186	3200
Farm #2								
SL 1	Corsoy	21.3	24062	9080	7790	16.7	6531	3070
SL 2	Corsoy	21.3	18160	6810	5820	14.9	5468	2570
Farm #3								
SL 1	Pioneer 9202	43.3	12712	4994	4680	11.0	5956	1380
SL 2	Pioneer 9202	43.3	23608	**6356 ϕ8971	5370 ϕ7579	13.1	5739 ϕ8100	1330 1870

*Lab. Grain Yield excludes bag

** Unknown weight lost because of thresher choke.

ϕ Adjusted weight using Grain Mass/Plant Mass Index of 0.38

TABLE A6.8

Measured Plant Heights, Planting and Harvesting Dates

arm	Planting Date	Harvest date	Plant Heights (mm)			
			1989 07 06	1989 07 27	1989 08 30	1989 09 24
#1	1989 05 22	1989 10 02	203 - 355	483 - 686	635 - 762	457 - 889
#2	1989 06 10	1989 10 02	152 - 203	254 - 406	457 - 762	305 - 711
#3	1989 05 11	1989 09 28	site not yet identified	355 - 406	381 - 534	381 - 406

Table A6.9 Laboratory Moisture Contents and Densities, 1989

Farm #	1	1	3	3	3	3	3	3
Depth (mm)	200	200	100	100	200	100	100	200
Sample #	2/1	2/1	2/1	2/1	2/1	1	1	23
MC(%)	19.87	19.23	14.88	15.20	21.24	16.31	16.29	19.20
DD (Mg/m^3)	1.381	1.342	1.565	1.623	1.468	1.563	1.547	1.599
SF(%)	16.50	18.10	7.50	9.10	23.60	6.68	11.30	9.63

Farm #	3	3	3	3	1	1	1	1	2
Depth (mm)	100	100	200	200	100	100	100	100	200
Sample #	12	12	3	3	2/1	2/1	2/2m	2/2m	2/2m
MC(%)	13.14	12.52	18.71	23.11	18.11	19.79	21.60	22.98	23.57
DD (Mg/m^3)	1.705	1.474	1.513	1.451	1.316	1.424	1.405	1.398	1.386
SF(%)	6.65	6.95	14.65	19.85	9.57	17.70	16.10	21.35	26.20

Farm #	2	2	2	2	2	2	2	2
Depth (mm)7	200	100	200	200	100	100	100	200
Sample #	2/2m	2/3	1/1	1/1	1/1	1/1	1/2	2/1m
MC(%)	23.38	20.97	20.63	22.60	21.09	22.28	21.57	28.64
DD (Mg/m^3)	1.457	1.538	1.488	1.542	1.528	1.503	1.531	1.402
SF(%)	15.90	19.38	20.85	17.90	18.50	22.55	16.50	25.70

MC Moisture Content
DD Dry Density
SF Shrinkage

Table A6.10
Field and Laboratory Measurements
of Moisture Content & Dry Density, 1989

Dry Density, Mg/cu.m		Moisture Content, %					
All Farms		Farm1		Farm2		Farm3	
		4" Depth		4" Depth		4" Depth	
Lab	Troxler	Lab	Troxler	Lab	Troxler	Lab	Troxler
1.362	1.394	13.75	19.44	16.4	20.26	20.8	20.84
1.516	1.508	16.6	20.62	15.1	20.4	22.3	24.49
1.531	1.514	15.3	19.4	15.1	23.62	20.5	22.49
1.402	1.396	13.4	18.3	16	23.4	24.6	24.12
1.474	1.477	26.4	29.97	27.1	27.18	23	23.04
1.482	1.45	24.6	25.85	22.9	26.77	22.7	24
1.37	1.303	21.9	26.98	18	18.76	17	14
1.401	1.36	24.6	27.46	25.2	24.08	20.2	20.3
		21.8	24.6	21.2	22.55	16.4	14.8
		19.6	19	21.4	22.1	18.3	16.9
		21.7	22.2	18.1	20.6	20.8	19
		18.4	19.8	24.6	24		
		18.9	17.8	16.8	17.4		
		19	19.7	15.7	21.2		
		8"Depth		8"Depth		8"Depth	
		12.4	21.94	15.9	22.1	19.8	22.82
		15.3	18.2	16.8	21.1	21.2	21.94
		14	20.07	14.3	22.4	17.4	20.59
		13.1	19.5	15.3	27.1	22.3	18.89
		25.2	29.5	26.5	27.4	21.5	21.29
		21.2	24.18	24.8	25.83	20.8	22.56
		23.7	22.75	18.1	23.35	15.9	21.2
		20.9	26.4	21.1	27.76	18.8	13.1
		19.1	23.34	18.5	22.8	15.8	17
		16.9	24.7	20.3	21.2	16.3	18.1
		19.9	24.3	18.3	20.8	19.6	21.7
		16.2	21.3	25	24.2		
		15	21.4	14	23.8		
		16.3	24	15.8	21.4		

Table A6.11: Laboratory Values of Moisture Content, Dry Density and Shrinkage - 1990

		April 25		June 25		July 13	
Sample		SCT1	SCT2	SCT3	SCT4	SCT5	SCT6
Moisture Content	%	27.3	26.5	16.4	17.0	11.2	9.1
Dry Density(DD)	kg/m3	1390	1466	1607	1813	1757	1686
SHRINKAGE	%	17.26	17.24	6.79	6.88	2.73	3.45

				April 25			
Location		1	1	1M	1M	2	2
Depth		4"	8"	4"	8"	4"	8"
Moisture Content	%	22.6	22.9	24.1	20.2	24.9	25.0
Dry Density(DD)	kg/m3	1558	1557	1503	1577	1508	1530
SHRINKAGE	%	12.02	12.70	13.79	12.20	15.28	16.11

				April 25		
Location		2M	3	3	control	
Depth		4"	4"	8"	4"	8"
Moisture Content	%	25.4	25.8	26.6	22.4	23.2
Dry Density(DD)	kg/m3	1531	1460	1396	1549	1566
SHRINKAGE	%	15.83	17.82	20.84	13.46	15.33

		April 25			
Location		random1		random2	
Depth		4"	8"	4"	8"
Moisture Content	%	29.0	27.8	26.0	22.3
Dry Density(DD)	kg/m3	1450	1434	1443	1523
SHRINKAGE	%	19.18	18.69	17.40	16.78

		June 02		
Location		2	1	2M
Depth		4"	4"	4"
Moisture Content	%	17.0	17.0	19.0
Dry Density(DD)	kg/m3	1705	1614	1644
SHRINKAGE	%	--	--	--

				June 25			
Location		1	2	control1		control2	
Depth		4"	4"	4"	8"	4"	8"
Moisture Content	%	20.9	20.0	18.0	17.1	20.0	16.0
Dry Density(DD)	kg/m3	1425	1501	1640	1770	1568	1697
SHRINKAGE	%	--	--	--	--	--	--

		July 13
Location		control
Depth		4"
Moisture Content	%	14.0
Dry Density(DD)	kg/m3	1710
SHRINKAGE	%	3.10

Table A6.12 Atterberg Limits

Farm #	Sample	Depth (mm)	LL	PL	PI
1	1	100	40.4	18.0	22.4
	2	100	40.4	20.6	19.8
	3	200	42.3	21.6	20.7
	4	200	40.5	19.5	21.0
2	1	100	43.0	19.0	24.0
	2	100	37.2	19.2	18.0
	3	200	35.2	18.2	17.0
	4	200	35.9	20.9	15.0
3	1	100	38.3	18.0	20.3
	2	100	34.8	16.0	18.8
	3	200	35.5	18.2	17.3
	4	200	32.8	17.3	15.5
C	1	100	41.3	22.3	19.0
	2	100	41.8	21.5	20.3
	3	200	33.9	21.3	23.6
	4	200	46.0	22.5	23.5

C - Combined Sample, Farm #1, #2, #3
LL - Liquid Limit
PL - Plastic Limit
PI - Plasticity Index

Table A6.13 Specific Gravity Determinations

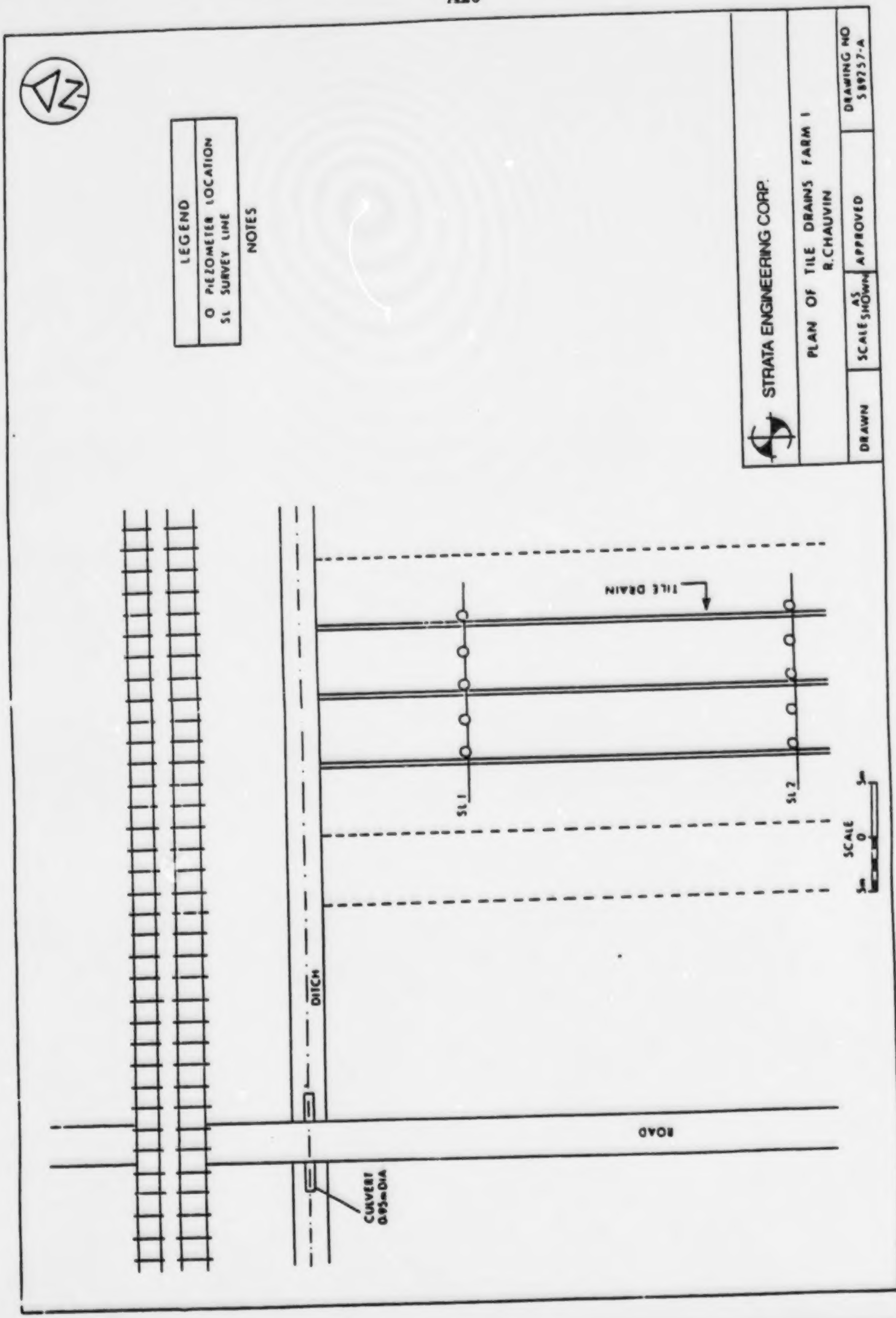
Farm #	Depth (mm)	Specific Gravity
1	100	2.600
1	200	2.558
1	375 - 450	2.689
1	850	2.689
2	100	2.596
2	200	2.550
3	100	2.606
3	200	2.585

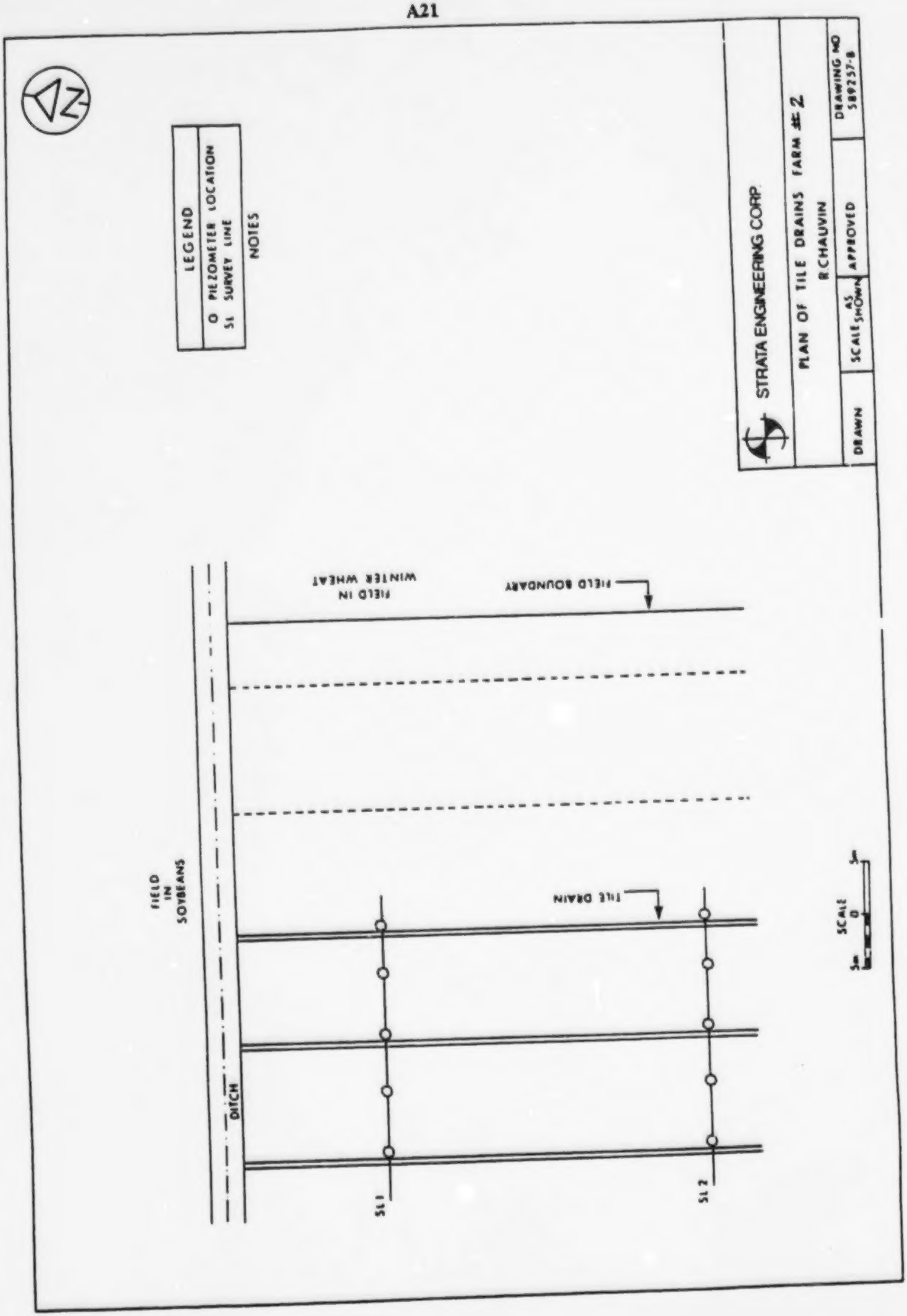
Mean Specific Gravity = 2.610
Standard Deviation σ = 0.051

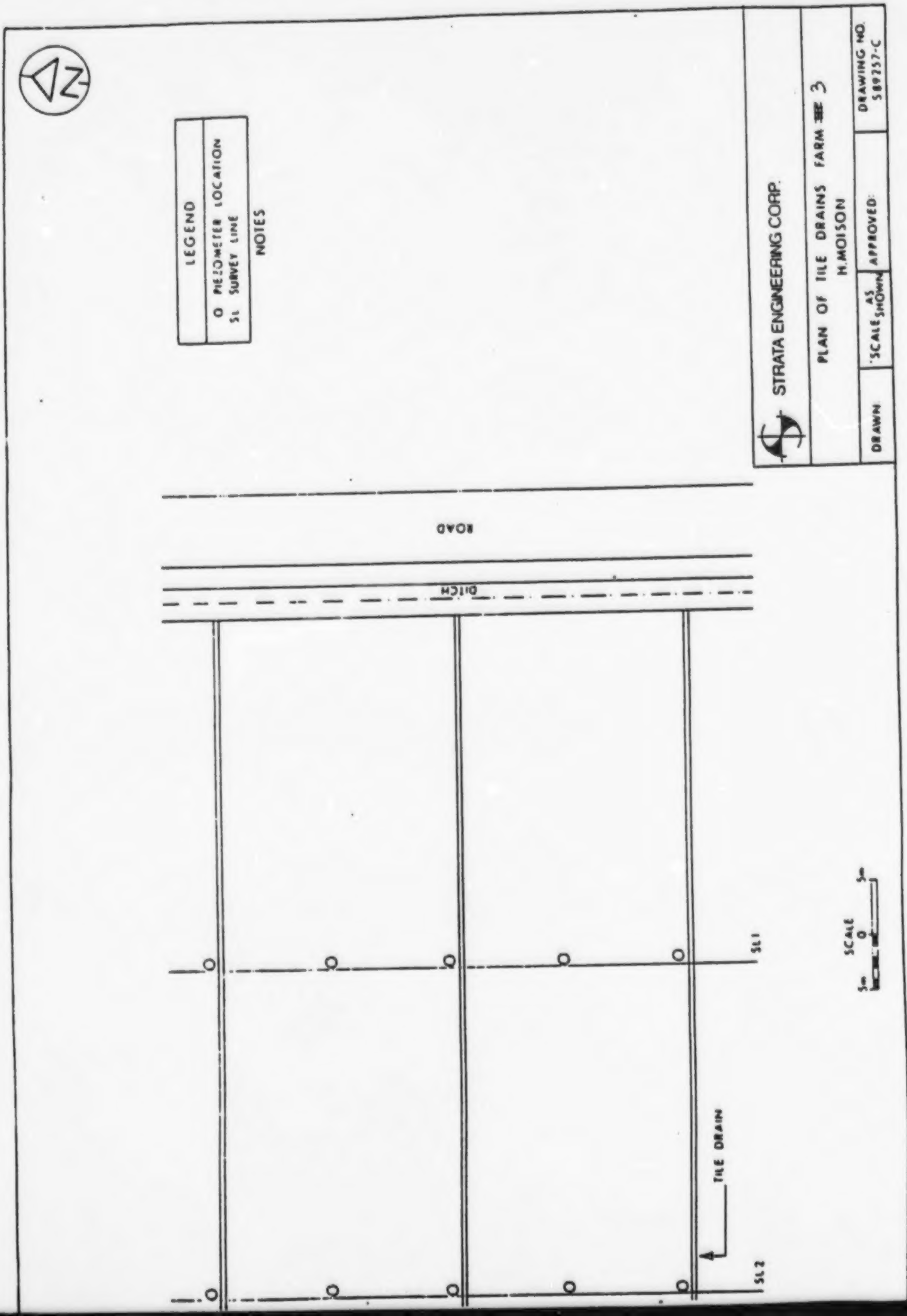
Table A6.14 Proctor Density Results

Farm #	Proctor Test	Optimum Moisture Content Compaction (%)	Remarks
1	S	19.7	SL 1
	M	21.0	SL 1
1	S	20.5	SL 2
	M	23.2	SL 2
3	S	19.0	0 - 100mm Depth
	M	20.0	0 - 100mm Depth
3	S	19.5	100 - 375mm Depth
	M	21.0	100 - 375mm Depth
C	S	18.5	Composite Sample
	M	20.0	Composite Sample

C - Composite Sample
S - Standard Proctor Test (25 blows)
M - "Modified" Proctor Test (10 blows)


LEGEND
O PIEZOMETER LOCATION
SL SURVEY LINE
NOTES
STRATA ENGINEERING CORP.
PLAN OF TILE DRAINS FARM 1
R.CHAUVIN
DRAWN
SCALE AS SHOWN
APPROVED
DRAWING NO
S89257-A
TILE DRAIN
SL 1
SL 2
SCALE
5m
0
5m
DITCH
ROAD
CULVERT
0.95m DIA

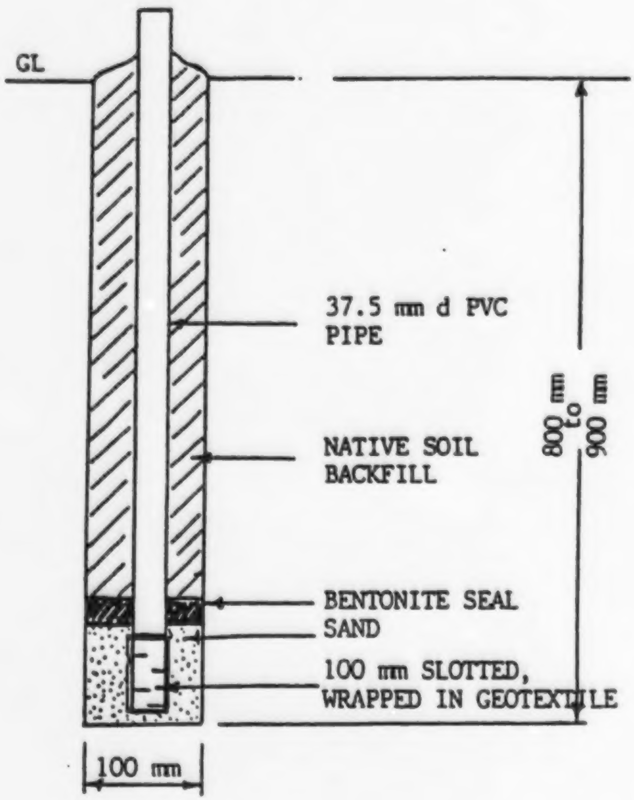

LEGEND
O PIEZOMETER LOCATION
SL SURVEY LINE
NOTES
FIELD IN WINTER WHEAT
FIELD BOUNDARY
FIELD IN SOYBEANS
TILE DRAIN
DITCH
SL 1
SL 2
SCALE
STRATA ENGINEERING CORP.
PLAN OF TILE DRAINS FARM #2
R.CHAUVIN
DRAWN
SCALE AS SHOWN
APPROVED
DRAWING NO



LEGEND
O PIEZOMETER LOCATION
SL SURVEY LINE
NOTES
STRATA ENGINEERING CORP.
PLAN OF TILE DRAINS FARM # 3
H.MOISON
DRAWN
SCALE AS SHOWN
APPROVED:
DRAWING NO. S89257-C
ROAD
DITCH
TILE DRAIN
SL1
SL2
SCALE
5m
0
5m


DRAIN
39m TO ROAD
P1
P2
T1
P3
T2
P4
T3
T4
TILE DRAIN
TILE DRAIN
TILE DRAIN
LEGEND
PIEZOMETER LOCATION
TENSIOMETER LOCATION
SCALE
1m 0 1m
STRATA ENGINEERING CORP.
LAYOUT PLAN OF PIEZOMETERS & TENSIOMETERS FARM1 R.CHAUVIN
DRAWN: AK
SCALE: AS SHOWN
DATE: 110690
APPROVED:
DRAWING NO 589257-D

STRATA ENGINEERING CORP.
CONSULTING ENGINEERS & GEOTECHNICAL SPECIALISTS



GENERALISED PIEZOMETER ARRANGEMENT

S-89-257 AGRICULTURE CANADA

Drawn MP	Date 1990 03 12	Scale not to scale	Sketch No. S 89257-SK-1

Table M.1 Field Visit Schedule

Dates	Reason for Visit	Personnel	Remarks
1989 05 31	Startup meeting	CM,MP	Attended start up meeting at Harrow.
1989 06 01			Toured TED sites
1989 06 12	Site Selection	MP	Visits to Stoney Pt. Tilbury Conc. 3 and St. Joachim
1989 06 22	Site Selection	MP	Visits to Stoney Pt. Tilbury Conc. 3 and St. Joachim
1989 07 04	Instrument'n. &	MP,CM	Locate drain tiles, set out survey lines,
1989 07 05	Site Selection	SS	Install piezometers on farms #1 & #2
1989 07 06		MP	Select Farm #3
1989 07 07			
1989 07 13	Instrumentation	MP,SS	Complete piezometer installation on
1989 07 14			Farm #2. Measurements, Farm #1 Locate tile drains Farm #3.
1989 07 26	Instrumentation	MP,SS	Installed piezometer on Farm #3.
		DM	Measurements on Farms #1 and #2
1989 08 17	Measurements	MP	Hydraulic conductivity test, Farm #1 Piezometric readings, Farm #1.
1989 08 03	Measurements	MP,SS	Measurements, all Farms. Rainfall data
1989 08 31	Measurements	SS	Measurements on all Farms.
1989 09 24	Measurements	SS	Measurements on all Farms. Contact Co-op Agronomist
1989 09 28	Measurements	MP,SS	Harvesting on Farm #3
1989 10 02	Measurements	MP,SS	Harvesting on Farms #1 and #2
1989 11 10	Measurements	MP	Rainfall, cultivation, Farms #1,2 & 3
1989 11 28	Measurements	SS	Measurements of compaction & soil moisture in control areas
1990 04 25	Instrumentation	MP,SS	Install Piezometers on Farm #1
1990 04 26	Measurements		Crack Monitoring
1990 06 01	Measurements	SS	Density, Instruments Farm #1
1990 06 02			
1990 06 25	Measurements	MP,SS	Density, Cracks

Table M.1 Field Visit Schedule - continued

Date	Reason for Visit	Personnel	Remarks
1990 07 09	Measurements	MP	Hyd. Conductivity, Farm #3
1990 07 13 1990 07 14	Measurements	SS	Density, Cracks

Personnel:

MP - Michael J. Percy
SS - Shan Shanmugganantha
CM - Cameran Mirza
DM - Donald A. Mullett

Inspection report for Strata Engineering Corporation

Attention : Mr. Shan Shanmuganatha

Dear Shan,

As per your request I inspected the fields of Robert Chauvin and Hermas Moison.

Robert Chauvin (HOME FARM)

(1) In this field there was two varieties of soybean planted. In talking with Robert I came to find out that the headlands were planted with NK S2424 and the field was Pioneer 9202.

There seems to be a considerable difference between the two, the Pioneer variety being shorter more stunted from the earlier rains.

(2) The crop seems to be fairly clear of pest and disease.

(3) Estimated yield is approx. 45 - 50 bu/ac.

(4) Depending on the location of the yield test the results could differ because of the different varieties and water damage.

The weed control in the field is fair.

Robert Chauvin (RENTED FARM)

(1) This field was in fairly good condition. It was planted with a Corsoy variety soybean. There was evidence of a little water damage in isolated pockets in the field.

(2) The crop seems to be fairly clear of pests and disease, a little grasshopper damage along the headland at the tracks.

(3) Estimated yield is approx. 35 - 40 bu/ac.

Hermas Moison (MOTHER'S FARM)

(1) The crop was 9202 Pioneer soybeans. There was considerable water damage making the plants short stunted and podded very low to the ground.

(2) The crop was clear of pest and disease and also weed free.

(3) Estimated yield here is approx. 20 - 25 bu. if he's lucky.

(4) I believe the problem here was variety related. All 9202 in the area seem to have a problem handling all the early water we received.

Leo Guilbeault
Crop Specialist
Stoney Point Cocp.
(519) 798-3011

TROXLER MODEL 3440

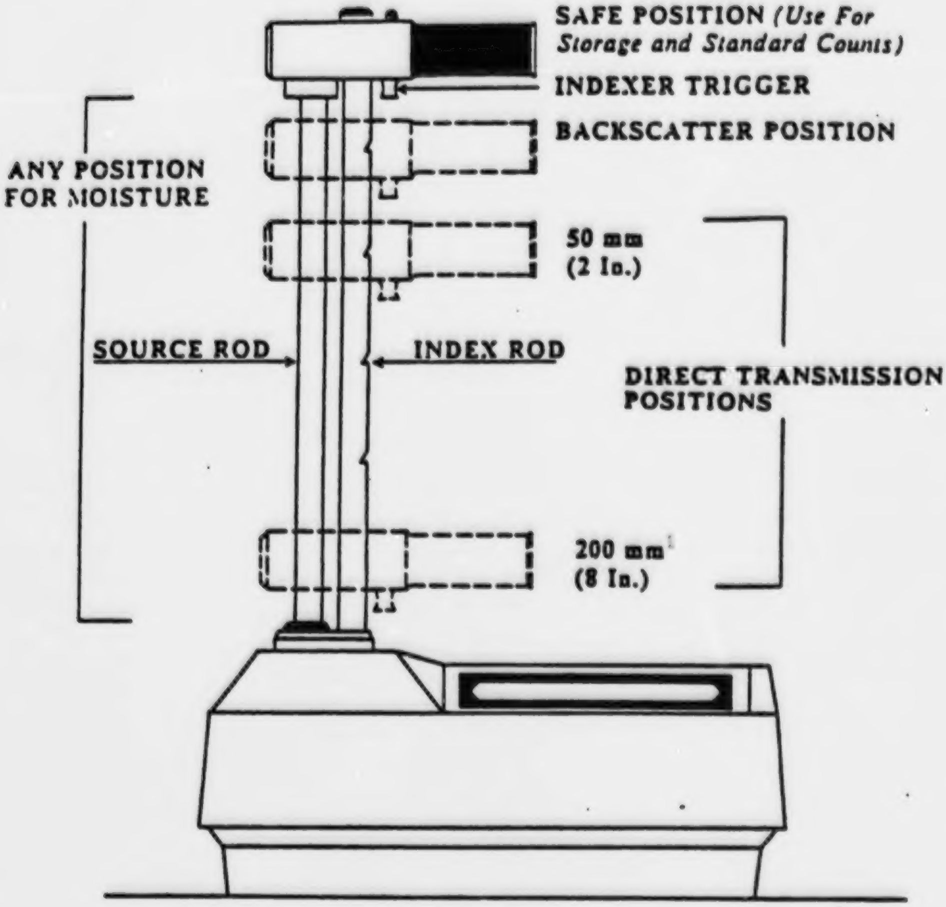


FIGURE 3
GAUGE SHOWING ROD POSITIONS [1]

[1] *The 8 inch (200mm) model is illustrated; the Troxler Model 3440 is also available in a 12 inch (300mm) model.*

MEASUREMENT SPECIFICATIONS U.S. CUSTOMARY UNITS

Direct Transmission, 6 inches	15 sec.	1 min.	4 min.
Precision at 125 PCF	±0.42 PCF	±0.21 PCF	±0.11 PCF
Composition Error at 125 PCF	±1.25 PCF	±1.25 PCF	±1.25 PCF
Surface Error (0.05 inch, 100% Void)	-0.87 PCF	-0.87 PCF	-0.87 PCF
Backscatter Density (98%) 4 inches			
Precision at 125 PCF	±1.00 PCF	±0.50 PCF	±0.25 PCF
Composition Error at 125 PCF	±2.50 PCF	±2.50 PCF	±2.50 PCF
Surface Error (0.05 inch, 100% Void)	-3.43 PCF	-3.43 PCF	-3.43 PCF
Moisture			
Precision at 15 PCF	±0.64 PCF	±0.32 PCF	±0.16 PCF
Surface Error (0.05 inch, 100% Void)	-1.12 PCF	-1.12 PCF	-1.12 PCF

Depth of Measurement at 15 PCF - 6 inches

MEASUREMENT SPECIFICATIONS S.I. UNITS

Direct Transmission, 6 in. (150mm)	15 sec.	1 min.	4 min.
Precision at 2000 kg/m^3	±6.8 kg/m^3	±3.4 kg/m^3	±1.7 kg/m^3
Composition Error at 2000 kg/m^3	±20.0 kg/m^3	±20.0 kg/m^3	±20.0 kg/m^3
Surface Error (1.25 mm, 100% Void)	-14.0 kg/m^3	-14.0 kg/m^3	-14.0 kg/m^3
Backscatter Density (98%) 100mm			
Precision at 2000 kg/m^3	±16.0 kg/m^3	±8.0 kg/m^3	±4.0 kg/m^3
Composition Error at 2000 kg/m^3	±40.0 kg/m^3	±40.0 kg/m^3	±40.0 kg/m^3
Surface Error (1.25 mm, 100% Void)	-55.0 kg/m^3	-55.0 kg/m^3	-55.0 kg/m^3
Moisture			
Precision at 240 kg/m^3	±10.0 kg/m^3	±5.0 kg/m^3	±2.5 kg/m^3
Surface Error (1.25 mm, 100% Void)	-18.0 kg/m^3	-18.0 kg/m^3	-18.0 kg/m^3

Depth of Measurement at 240 kg/m^3 - 150 mm

PERIODIC MAINTENANCE AND SERVICE - SPECIFICATIONS (Continued)

CALIBRATION SPECIFICATIONS

Density Standards Accuracy :	± 0.3%
Moisture Standards Accuracy:	± 2.0%
Calibration Range :	70-170 PCF (1100-2700 kg/m^3) Density 0-40 PCF (0-640 kg/m^3) Moisture

Method: Computer reduction of count rate data based on U.S. National Bureau of Standards Electron Cross Sections, Neutron Cross Sections and Absorption Coefficients. Data is reduced to the form $D = (1/B)\ln(A/(CR + C))$ for density and $M = (CR - E)/F$ for moisture where A, B, C, E, and F are constants and CR is count ratio. The algorithm corrects for hydrogen photon scattering coefficients and provides means for offsetting non-water hydrogen. Direct calibration entry by keypad.

Special Functions
Automatic Standard Count Comparison and Storage
Determination of count time for selected precision.
Field offsets of density and moisture data.
Field Calibration for special soil types.
Nomograph method for measurement of asphalt overlays.
Method to negate effects of sidewall moisture in a trench.

FIELD DATA CONVERSION

Contains uP (Microprocessor) providing direct reading in both US and SI. Customary Units for wet density, dry density, moisture content and percent moisture. The algorithm corrects for hydrogen photon scattering coefficients and provides means for offsetting non-water hydrogen.

If theoretical densities are preset by operator, the uP can compute % of Marshall/Voids (Asphalt mode) or % of Proctor (Soil mode).

RADIOLOGICAL SPECIFICATIONS

Gamma Source and Dwg. No.	8 ±1 mCi Cesium-137, TEL A-102112
Neutron Source and Dwg. No.	40 ±10% mCi Americium-241:Beryllium, TEL A-102451
Source Housing	Stainless Steel, Double Encapsulated
Shielding	Tungsten, Lead and Cadmium
Surface Dose Rates	20 mRem/hour max., neutron and gamma
Source Rod Material	Stainless Steel
Shipping Case	DOT 7A, Type A, Yellow II label, 0.5 Transport Index
Source Sealed approval for Domestic and International Shipment	Cs-137, SPECIAL FORM Certificate; GB: SFC 140 Am-241:Be, SPECIAL FORM Certificate; GB: SFC 7

COMMUNICATION SPECIFICATIONS

Serial Port	RS-232 (Field Selectable 300 to 4800 Baud)
Parallel Port	General Purpose Expansion Port

PERIODIC MAINTENANCE AND SERVICE - SPECIFICATIONS (Continued)

MEMORY SPECIFICATIONS

RAM	64K Resident, Non-Volatile; Stores over 450 complete station records. 192K External.
ROM	256K or 512K Resident, 512K External.

ELECTRICAL SPECIFICATIONS

Time Accuracy and Stability	$\pm$ 0.005% $\pm$ 0.0002%/° C
Power Supply Stability	$\pm$ 0.01%° C
Stored Power	30 watt-hours
Battery Recharge Time	16 hours, Automatic cutoff
Charge Source	110/220 VAC, 50-60 Hz. or 12-14 VDC
Liquid Crystal Display (LCD) Readout	4 x 16 Alpha-numeric
Power Consumption (watts) Average	0.16
Power Consumption after automatic Battery Cutoff (watts)	0.00

Gauge returns to Gauge Ready (power saving mode) after 2 min. of operator inactivity, except in STD, STAT TEST, DRIFT TEST, and NOMOGRAPH (30 Min.). After 5 hours of complete inactivity, gauge performs a total power shut-down.

Battery Packs are fully protected against overcharge and overdischarge; charge life is updated every 1.9 seconds and is indicated on the (READY) display.

Emergency Use - Capable of Operation with six (6) "D" size Alkaline Batteries. Not all D size alkaline batteries will fit.

SELFTEST SERVICE PROGRAMS

- Display Test
- Keypad Test
- RAM Test
- He_3 and GM Tube test
- Statistical Stability and Drift Test
- Gauge Identification Program

MECHANICAL SPECIFICATIONS

Case	Polycarbonate top/aluminum cast base.
Vibration Test	0.1 inches (2.54 mm) at 12.5 Hz
Drop Test	300 mm on 25 mm diameter steel ball
Operating Temperature - Ambient:	14 to 158°F (-10 to 70°C)
- Surface:	350°F (175°C)
Storage Temperature	-70 to 185°F (-55 to 85°C)
Gauge Size *(excluding handles)*	14.8 x 9.1 x 7.2" (376 x 231 x 183mm)
Gauge Height *(including handles)*	12" - 19.5" (495mm) or, 8" - 15.5" (395mm)
Weight	29 pounds (13.15 kg)
Shipping Weight	90 pounds (40.8 kg) with transport case

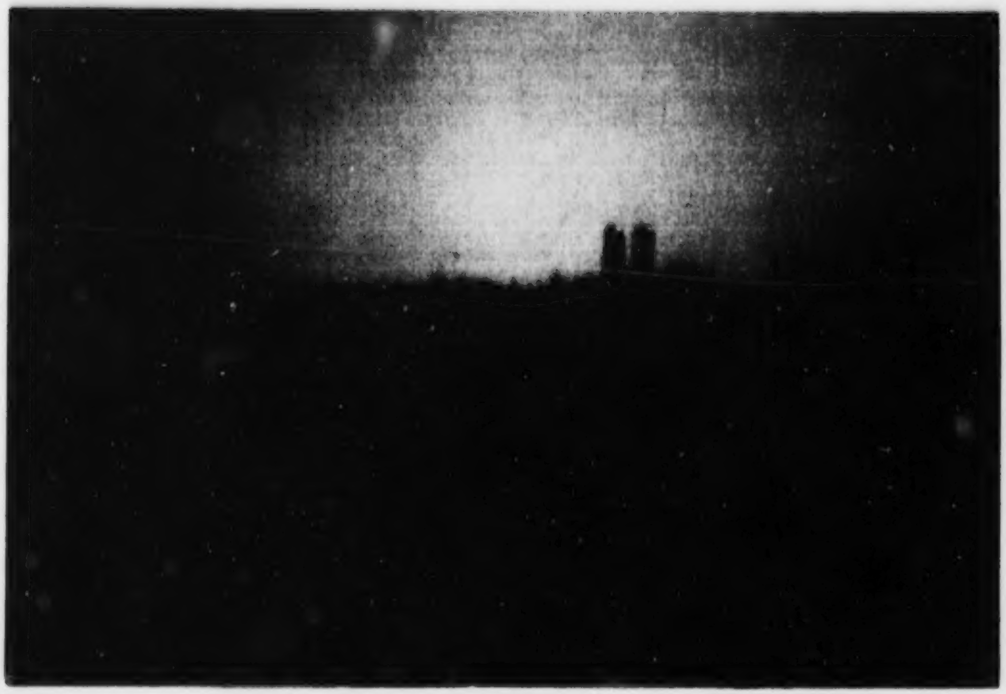


Plate 1 - Farm #1 General Layout, 1989

Plate 2 - Piezometer Tube, Bentonite, Sand

Plate 3 - Soil Cracking
Farm #1 July 1989

Plate 4 - 300mm Deep Crack. Farm #1 1990

Plate 5 - Soil Cracking Farm #1 July 13th, 1990

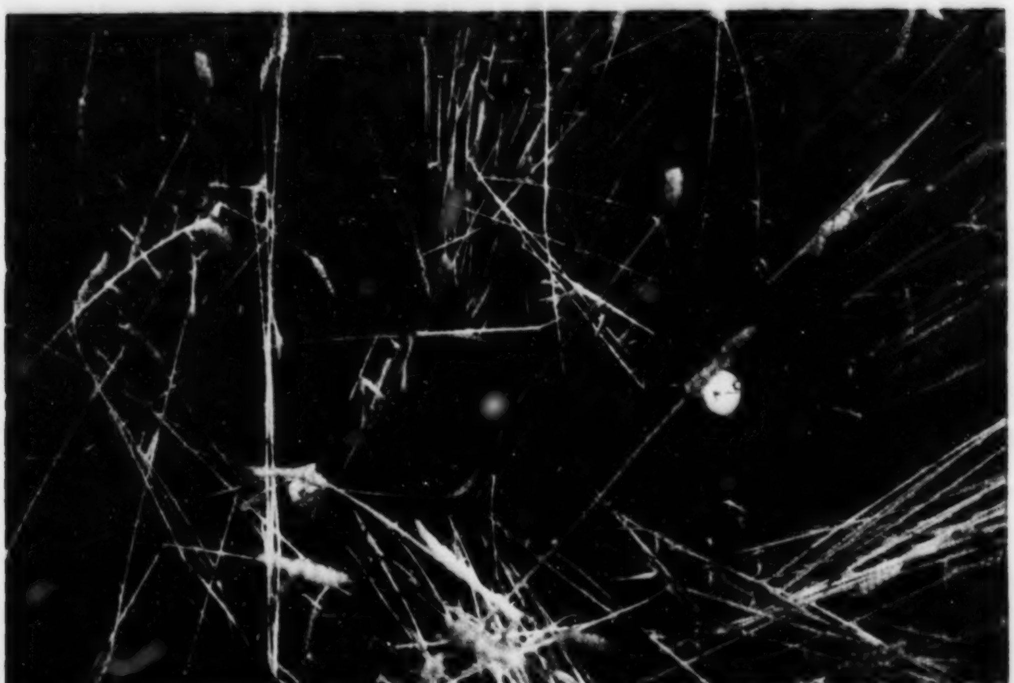


Plate 6 - Tensiometer Installation Farm #1 1990

Plate 7 - Jet Fill Tensiometer
Installed Farm #1 1990

Plate 8 - Piezometer and Tensiometer
Installations adjacent to
Tile Line Farm #1 1990

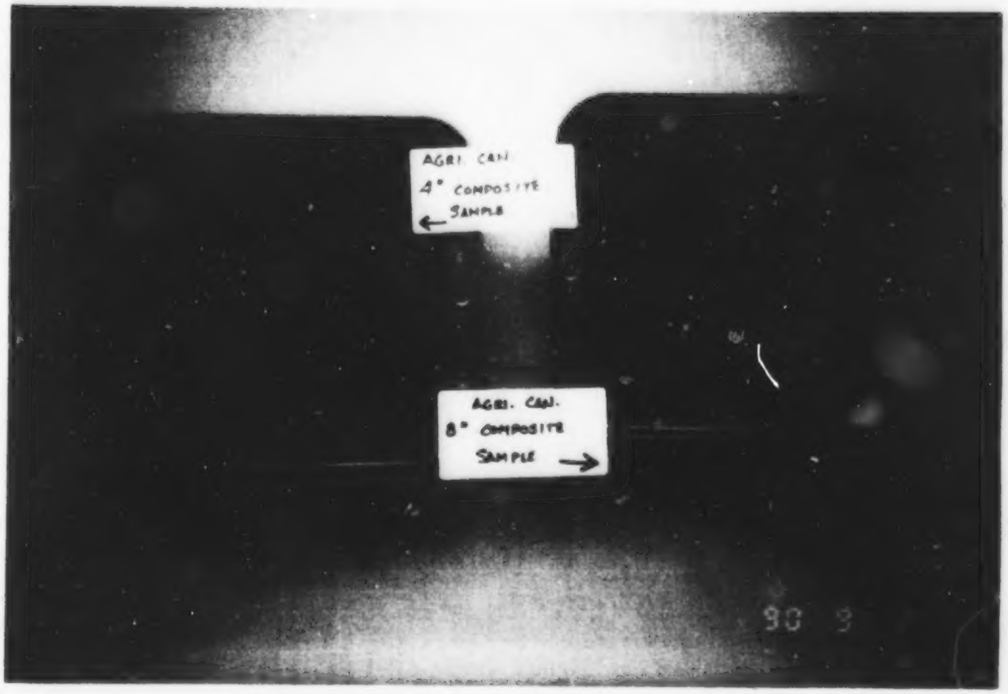


Plate 9 - Laboratory Soil Crack Tests; Developing Soil Cracks

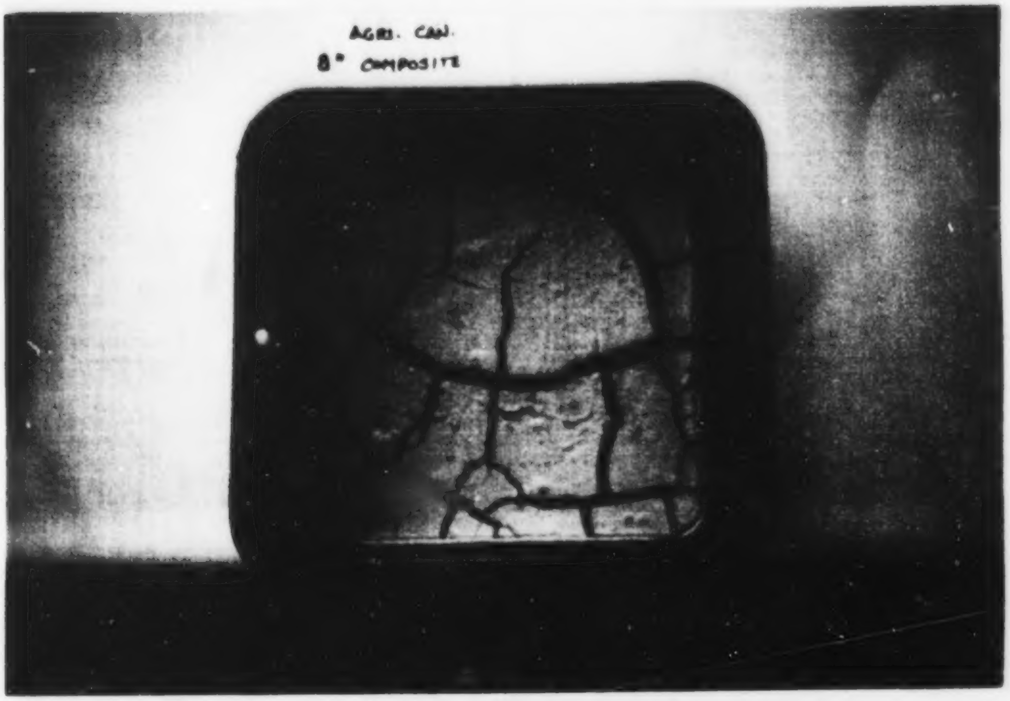


Plate 10 - Laboratory Soil Crack Tests; Developed Soil Cracks